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INTEGRATED SOLUTIONS DEVELOPMENT

CAPITAL SOLUTIONS INTERIM REPORT
VOLUME I: REPORT

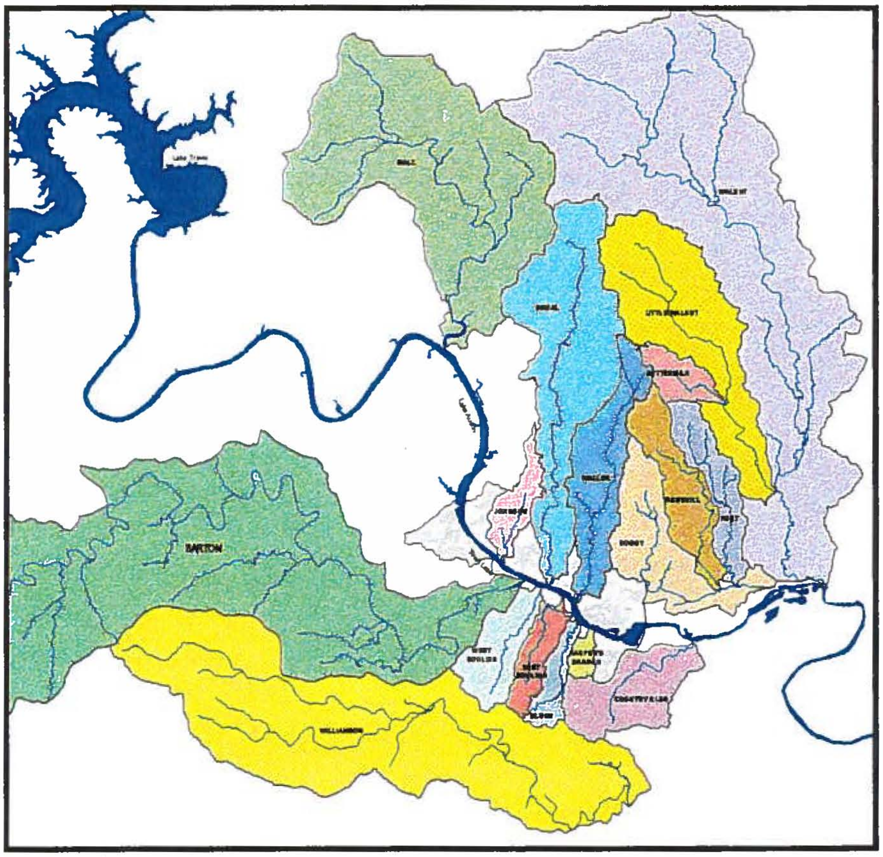

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TABLE OF CONTENTS

TABLE OF TABLES

Tables

Appendices

Appendix A: Water Quality

Appendix B: Flooding

Appendix C: Erosion

TABLE OF FIGURES

Figures

1.0 Introduction

The City of Austin is rich in water resources. Within its boundaries lie Barton Creek and Barton Springs, Town Lake and Lake Austin, McKinney Falls, and the Colorado River. In recent decades, as Austin has grown to become the nation's 23rd largest city, the consequences of human activity have included fundamental changes to many of its waterways that, not so long ago, were home to robust swimming pools and fishing holes. It is reported that in the 1950's, a swimming hole on Shoal Creek located immediately upstream of Koenig Lane in what is now Allendale was a popular and safe location for recreation. Today, trash and debris, channelization to relieve deadly flood risks, revetment to alleviate an aggressive erosion potential, high bacteria levels, and dangerous, high velocity storm flows have eliminated the recreational value of this swimming hole and other similar water resources.

In response to these continuing consequences of development, the Watershed Protection Department of the City of Austin has defined as a primary mission the prevention and remediation of flood, erosion and water quality degradation in the City's creeks. In 19__, the consulting firm Camp, Dresser and McKee (CDM) was hired by the Watershed Protection to direct Master Planning efforts aimed at developing and defining an effective strategy for water resources management in the City of Austin. Under the direction of Watershed Protection Department staff and CDM, consultants Raymond Chan & Associates and Loomis & Moore were hired to assist City staff and CDM in defining the character and magnitude of existing erosion and flood problems. Definition of the character and magnitude of water quality problems was carried out by Watershed Protection Department staff scientists and engineers.

In October, 1997, Loomis & Moore, in conjunction with a group of consultants and scientists, was engaged by the Watershed Protection Department to perform the "Integrated Solutions Development Study." This investigation incorporates and builds upon the large body of problem definition work previously undertaken by the City. It is designed to provide:

- systematic identification and evaluation of solution strategies for management of flood, erosion, and water quality problems;
- systematic optimization for strategies implementation stressing integration by problem type (flood, erosion, and water quality) and by solution type (CIP, regulatory, and operating programs);
- maximal flood, erosion, and water quality management benefits per unit cost;
- solutions evaluation targeting varying problem scales (local, reach, inter-reach, watershed, and citywide);
- selection of solutions targeting highly-rated problem areas;
- objective prioritization of specific capital, regulatory, and programmatic solutions;
- ~~definition of~~ stormwater management goals and assessment of goals attainment for varying levels and combinations of solutions implementation; and
- optimal solution implementation ordering.

The Integrated Solutions Development study addresses stormwater management solutions for the seventeen (17) "Phase I" watersheds. These include the central city and some surrounding areas. Twelve (12) of the watersheds are considered urban and five (5) are considered nonurban. The Phase I watersheds are presented in Figure 1-1 and include:

Urban Watersheds

1. Blunn Creek
2. Boggy Creek
3. Buttermilk Creek
4. Country Club Creek
5. East Bouldin Creek
6. Fort Branch
7. Harper's Branch
8. Johnson Creek
9. Shoal Creek
10. Tannehill Branch
11. Waller Creek
12. West Bouldin Creek

Nonurban Watersheds

1. Barton Creek
2. Bull Creek
3. Little Walnut Creek
4. Walnut Creek
5. Williamson Creek

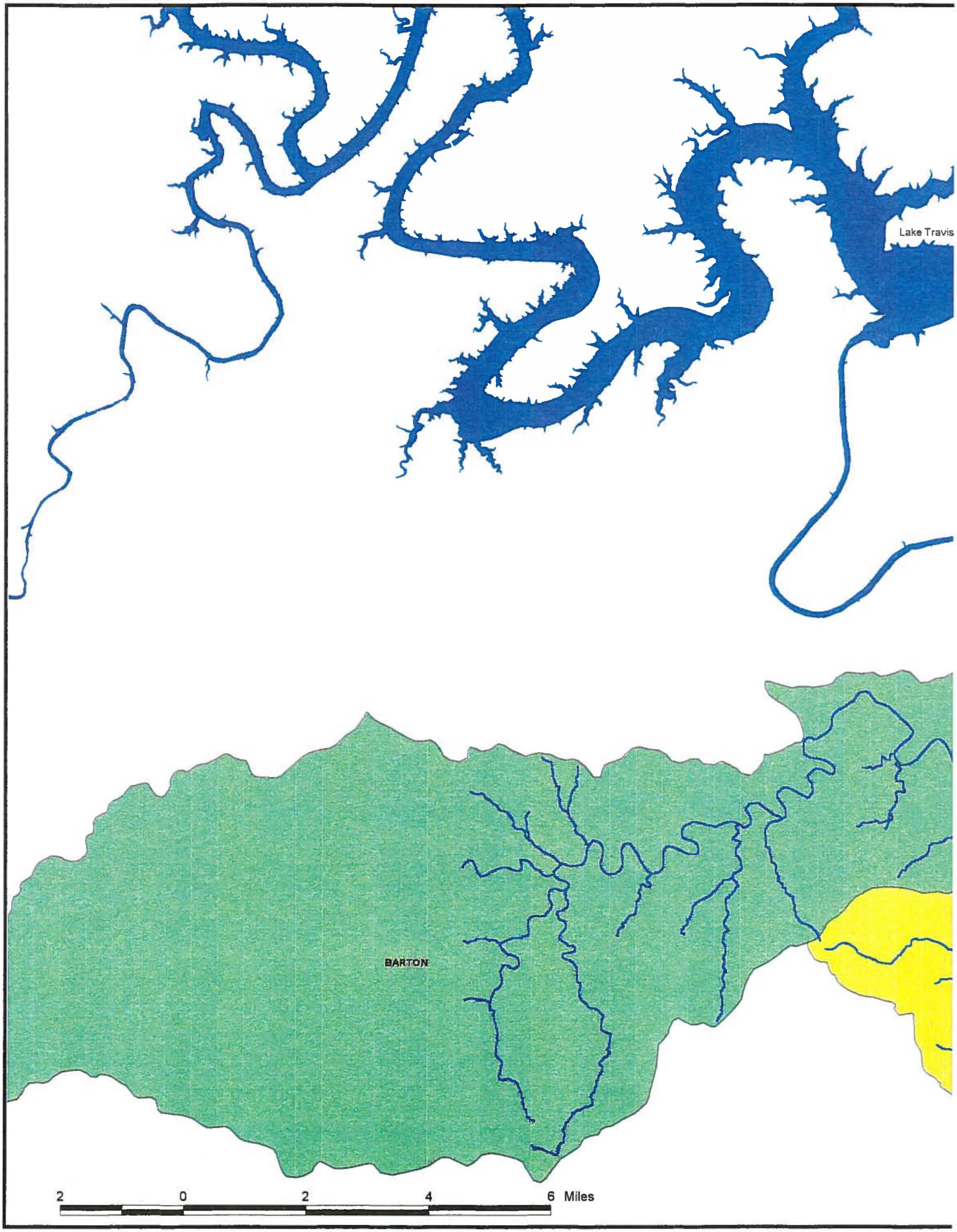
1.1 PROJECT APPROACH

The Integrated Solutions Development approach provides a logical and systematic procedure for defining optimal combinations of capital, regulatory, and programmatic solutions. This process promotes integration of solutions by problem type (flood, water quality and erosion) and by solution type (Capital Improvement Projects ["CIP projects"], regulations, and operating programs). The primary elements of the Integrated Solutions Development process include:

Solutions Inventory

The solutions development procedure begins with compilation of the *solutions inventory* in which the basic characteristics of all available capital project technologies, regulations, and operating programs are defined. This body of information represents the "state of the art" with respect to individual solution effectiveness, benefits, constraints, and applicability. This information serves in the current context to support preliminary and final project selection procedures.

Integrated Solutions Devel



Watershed

Stormwater Problems Identification

The character and magnitude of existing stormwater problems was investigated by City staff and multiple local consultant teams and was provided as input for the current solutions development investigation. Flood, erosion, and water quality problems were quantified and presented in units of problem score points defined individually by problem type for multiple discrete reaches in the 17 study watersheds. The flood, erosion, and water quality problem reach scores were also integrated (combined) to assist in the definition of problem locations where integrated solutions are appropriate.

Initial Solution Identification Protocols

Initial solution identification was performed to identify specific solution measures or types that are potentially effective and applicable for use in treating Austin's water quality, erosion, and flood problems. Initial screening of prospective solutions occurred through the development and application of the *~~Initial~~ Solutions Identification Protocols*. These protocols define the systematic procedure through which applicable prospective CIP, regulatory, and programmatic solution types are chosen for further evaluation in the feasibility level screening matrix.

Feasibility Level Screening

The *Feasibility Level Screening Matrix* is used to further refine the solutions selection process through objective comparison of a full range of problem and solution types. Comparison criteria include benefit scales and factors derived from the Watershed Protection Department's Interim Management Goals document. Separate screening matrices were developed for evaluation of capital projects, land acquisition initiatives, regulations, and operating programs. In each case, benefits are measured using benefit parameters that are equivalent for each benefit type and are compatible with solutions optimization decision variables employed in subsequent stages of the solutions development process. Application of the screening matrices yields prioritized listings ~~of the~~ evaluated programs, regulations, and CIP projects.

within each type

Conceptual Designs

For a limited number of higher-ranked CIP, regulatory, and operating programs solutions, "Conceptual Designs" are developed. The purpose of the conceptual designs is to provide a higher level of solutions definition. For Capital Improvement Projects, the conceptual designs present detailed physical configuration, cost, benefit, operations and maintenance, and map information. For the selected regulations and operating programs, conceptual designs include detailed solution descriptions, implementation costs, effects on existing regulations and programs, impacts on other City departments, impacts on other Watershed Protection Department objectives, and staffing requirements.

ORDER

Solutions Optimization

The primary goal of the "Integrated Solutions Development" process is to make the best use of the City's stormwater management resources. For the purposes of this investigation, "best use" is defined as the combinations of solutions which provide maximum benefits for a range of funding resource levels assuming relatively balanced solutions implementation by stormwater mission. Identification of optimal solutions combinations occurs through implementation of a systematic optimization procedure wherein varying combinations of solutions are applied and the value of an "objective function" is optimized. The objective function is comprised of multiple factors, each of which represents one or more Watershed Protection Department goals. The value of each factor is defined as the degree to which the goal or goals are met. The degree to which goals are met for varying combinations and levels of solutions application is calculated through implementation of the feasibility level screening matrices.

Goals Assessment

The final element of the Integrated Solutions Development investigation involves assessment of the practical ability of the Watershed Protection Department to meet its goals. Constraints on goals attainment may be financial (limited funding resources); technical (no amount of remedial measures application can meet the goals); and/or practical (the measures necessary to meet the goals would not be acceptable to the public and/or its policy makers). The goals assessment evaluation defines: (1) if the Watershed Protection Department goals can be met; (2) if they can, the optimal combination of solutions to meet them; and, (3) if they can not, the degree of goals attainment possible.

Figure 1-2 presents a flow chart describing the major components of the Integrated Solutions Development process.

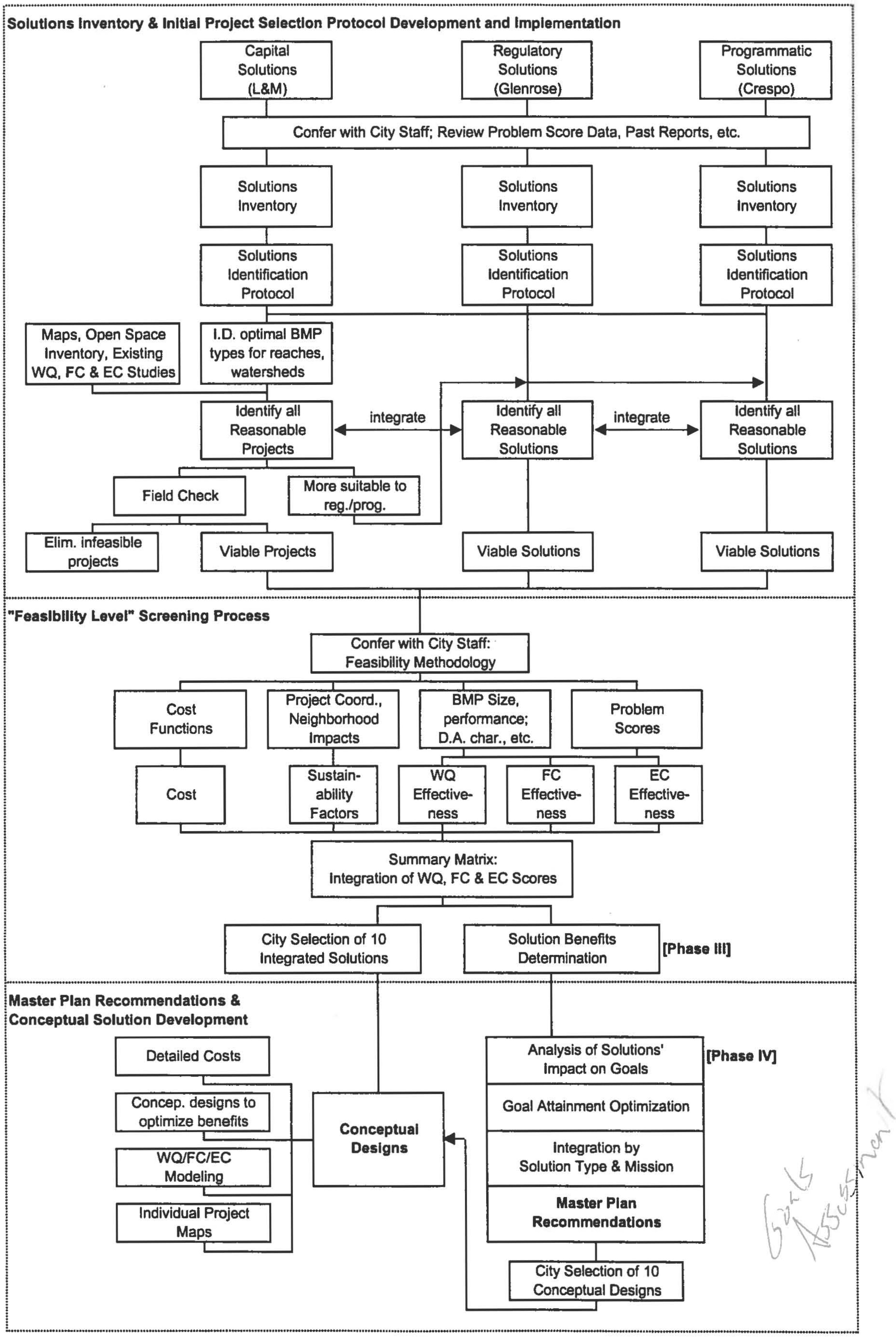
1.2 PROJECT TEAM AND SCOPE OF THIS REPORT

This report has been prepared by Loomis & Moore, in conjunction with a team of consulting engineers and scientists, for the City of Austin's Watershed Protection Department. Project team members and corresponding work performed include:

- **Loomis & Moore** –Project Manager and CIP Solutions Investigations
- **Crespo Consulting Services** - Investigations of Operating Program Solutions
- **Glenrose Engineering** - Investigations of Regulatory Solutions
- **Raymond Chan & Associates** - Investigation of Erosion Control Solutions
- **Center for Research in Water Resources (CRWR) at the University of Texas at Austin** - Watersheds Modeling and Solutions Optimization
- **Stonecreek Engineering** - Conceptual Designs

This report presents documentation of technical investigations performed for the Integrated Solutions Development project. The sections are arranged as follows:

Figure 1-2: Integrated Solutions Development Flow Chart of Project Activities



Section 2.0 – Problems Assessment.

Section 3.0 – Solutions Inventory.

Section 4.0 – Initial Solutions Identification (Initial Solutions Selection Protocols).

Section 5.0 – Solutions Feasibility Screening (Feasibility Level Screening Matrices).

Section 6.0 – Conceptual Designs Development.

Section 7.0 – Final Solutions Optimization, Compilation and Prioritization.

Section 8.0 – Goals Assessment.

Section 9.0 – Summary of Conclusions and Recommendations.

This study is Phase II of an overall investigation supporting development of the City of Austin Drainage Master Plan. This study investigates water quality solutions for the 17 "Phase I" watersheds. If implemented, a subsequent similar investigation will be performed for the 38?? additional "Phase II" watersheds.

2.0 Problem Areas Definition and Scoring

In anticipation of the solutions development process, the consultant team was provided by the Watershed Protection Department with stormwater problems data detailing the character and magnitude of stormwater problems in the study watersheds. The data includes a scoring methodology used to prioritize problems and account for varying resource values in the watersheds. This information has been developed by City staff and consultants over the past several years. It represents a thorough assessment of current and projected stormwater problems by stream reach or segment (subdivisions of watershed drainage areas or stream channels defined to provide an appropriate level of detail for analysis). Information provided by the Watershed Protection Department to the consultant team in support of the Integrated Solutions Development process is summarized below.

2.1 SUPPORT INFORMATION FROM THE WATER QUALITY PROBLEMS ASSESSMENT

The City of Austin presented the consultant team with a comprehensive set of water quality data for the 17 Phase I watersheds. This data enabled an objective prioritization of problem areas in the Master Plan. The data set and the scoring system used are described in the document "Water Quality Problem Area Scoring System for the Drainage Utility Masterplan: Phase 1 Watersheds" (COA ERM, November 1997).

For the water quality mission, the basic unit for prioritization is the EII Reach, defined as the stream reach and respective contributing drainage area between Environmental Integrity Index (EII) sites. EII sites are stations defined by City staff at which detailed information on stream condition was collected.

There were 70 EII Reaches defined for the Phase I watersheds. Water Quality Problem Scores were calculated for each EII reach. There were 47 EII reaches in the 12 urban watersheds, with the remaining 23 segments located in the 5 non-urban watersheds. The scoring system also accounts for 9 receiving waters (e.g., Town Lake, the Edwards Aquifer, etc.) to which the EII segments discharge. The "contribution" of each EII reach to a receiving water's problem score is accounted for using the ratio of the EII reach's drainage area to that of the receiving water. Table 2-1 presents the EII sites by watershed and the 9 receiving waters. Figure 2-1 shows the locations of the EII sites and receiving waters.

2.1.1 EII Scoring Methodology

The City developed overall EII reach problem scores based upon current and future problem assessments and relative contributions to receiving waters. The basic scoring equation used to calculate problem scores is as follows:

Table 2-1: Summary of Environmental Integrity Index (EII) Sites and Receiving Waters

Watershed	Abbrev.	No. of EII Sites	No. of EII Sites by Current Water Quality Condition					
			Excellent	Very Good	Good	Fair	Marginal	Poor
1. Barton Creek	BAR	5	1	4	0	0	0	0
2. Blunn Creek	BLU	4	0	0	2	2	0	0
3. Boggy Creek	BOG	4	0	0	1	2	1	0
4. Bull Creek	BUL	4	0	4	0	0	0	0
5. Buttermilk Creek	BMK	4	0	0	0	3	1	0
6. Country Club Creek	CNT	3	0	0	0	1	1	1
7. East Bouldin Creek	EBO	4	0	0	0	1	2	1
8. Fort Branch	FOR	4	0	0	1	2	1	0
9. Harper's Branch	HRP	3	0	0	0	1	2	0
10. Johnson Creek	JOH	4	0	0	0	1	0	3
11. Little Walnut Creek	LWA	4	0	0	2	2	0	0
12. Shoal Creek	SHL	4	0	0	1	2	1	0
13. Tannehill Branch	TAN	4	0	0	1	2	1	0
14. Waller Creek	WLR	4	0	0	1	2	1	0
15. Walnut Creek	WAL	5	0	0	5	0	0	0
16. West Bouldin Creek	WBO	4	0	0	0	1	2	1
17. Williamson Creek	WMS	6	0	0	2	3	1	0
Totals		70	1	8	16	25	14	6

Receiving Water	Resource Value Points
1. Lake Austin	100
2. Upper Town Lake	85/35 (Current/Future)*
3. Lower Town Lake	35
4. Colorado River below Longhorn Dam (to eastern edge of Austin ETJ)	30
5. Southern Edwards Aquifer	95
6. Barton Springs Pool	45
7. Barton Creek Watershed (all)	30
8. Bull Creek above Loop 360	30
9. McKinney Falls (east of Barton Springs Zone)	30
10. Creek Segments with "Excellent" EII Goals[1]	25
11. Creek Segments with "Very Good" EII Goals[2]	20
12. Creek Segments with "Good" EII Goals[3]	15

* It is assumed that the Green Water Treatment Plant will no longer be in service by the future Year 2040; without the public water supply function, its score will be lowered.

[1] Includes all reaches with current EII Condition of Excellent or Very Good

[2] Includes all reaches with current EII Condition of Good

[3] Includes all reaches with current EII Condition of lower than Good

$$\text{Problem Score} = \sum_{j}^{i} \{W_{cur}*RV*CPS*DAR) + (W_{fut}*RV*FPS*DAR)$$

where i = 1st receiving water, i+1 = 2nd receiving water, etc., to j = final receiving water
W_{cur} = Weight assigned to Current problems
RV = Resource Value
CPS = Current Problem Severity for the receiving water
DAR = Ratio of EII Reach drainage area to Receiving Water drainage area
W_{fut} = Weight assigned to Future problems
FPS = Future Problem Severity for the receiving water

Scores were normalized to fit a zero to 100 point scale. A score of 100 represents the highest concern and/or worst problem. A score of 0 indicates no current problems and with none anticipated for the future. Actual problem scores range from 4.7 to 100. The average problem score for all 70 segments was 41 with a standard deviation of 21. Table 2-2 presents a summary of EII reach problem scores by watershed. The current and future problem score components of the overall problem score were also normalized on a 0-100 scale and are presented in Table 2-2. In compiling the overall problem score, the current and future problems were equally weighted, i.e., $W_{cur} = W_{fut} = 0.50$.

Appendix A-1 presents overall problem scores and current and future problem scores for each of the 70 EII reaches. It also presents score breakdowns in terms of relative contribution of receiving waters and current vs. future conditions. Appendix D-1 presents plots of EII reach scores vs. creek station for Water Quality, Flood, Erosion, and Integrated (Weighted and Combined) Scores.

Table 2-1 shows the nine receiving waters evaluated with their respective Resource Values. These values reflect the number and quality of designated uses supported and the relative importance of each that the Citizens Advisory Group believes is appropriate. High resource values reflect community support of water supply, contact recreation, and public recreation uses associated with each receiving water.

Problem severity scores were calculated differently for each receiving water due to differing water quality goals and availability of data. Current problem severity scores were not calculated in exactly the same manner as were future problem severity scores because different information was available. However, future severity scoring factors were correlated to goals and current problems to the extent possible.

The main information used for calculating EII reach problem scores was as follows:

- Environmental Integrity Index (EII);
- Flow volumes, including baseflow for creeks, spring flow for Barton Springs – usually calculated or extrapolated from the CRWR model;
- Annual average pollutant loads (from the CRWR model). The following parameters are used for scoring purposes:
- * Sedimentation – Total Suspended Solids (TSS)
- * Nutrients – Total Nitrogen (TN), Total Phosphorus (TP), Total Organic Carbon (TOC)

Table 2-2: Summary of Water Quality Problem Scores by Watershed

Watershed	Abbrev.	No. of EII Sites	Current Prob. Score		Future Prob. Score		Totals		Rank of Avg. EII Score	Pct. Score Attrib. to Current vs. Future Conditions	
			Watershed Totals	Avg. EII	Watershed Totals	Avg. EII	Watershed Totals	Avg. EII		Current	Future
1. Barton Creek	BAR	5	143.5	28.7	214.9	43.0	358.5	71.7	4	42.5%	57.5%
2. Blunn Creek	BLU	4	100.9	25.2	65.1	16.3	166.0	41.5	12	53.5%	46.5%
3. Boggy Creek	BOG	4	137.6	34.4	25.8	6.4	163.4	40.8	13	84.6%	15.4%
4. Bull Creek	BUL	4	152.5	38.1	176.1	44.0	328.6	82.2	1	45.3%	54.7%
5. Buttermilk Creek	BMK	4	137.7	34.4	33.0	8.3	170.7	42.7	11	71.0%	29.0%
6. Country Club Creek	CNT	3	180.7	60.2	47.3	15.8	228.0	76.0	2	73.0%	27.0%
7. East Bouldin Creek	EBO	4	217.8	54.4	35.3	8.8	253.0	63.3	6	84.1%	15.9%
8. Fort Branch	FOR	4	135.6	33.9	38.8	9.7	174.4	43.6	10	77.4%	22.6%
9. Harper's Branch	HRP	3	104.5	34.8	13.9	4.6	118.4	39.5	15	72.8%	27.2%
10. Johnson Creek	JOH	4	289.9	72.5	5.8	1.5	295.7	73.9	3	97.7%	2.3%
11. Little Walnut Creek	LWA	4	83.3	20.8	42.0	10.5	125.3	31.3	17	58.6%	41.4%
12. Shoal Creek	SHL	4	143.0	35.7	34.7	8.7	177.6	44.4	9	77.1%	22.9%
13. Tannehill Creek	TAN	4	138.0	34.5	24.0	6.0	162.0	40.5	14	78.0%	22.0%
14. Waller Creek	WLR	4	124.5	31.1	18.9	4.7	143.4	35.9	16	84.1%	15.9%
15. Walnut Creek	WAL	5	164.4	32.9	157.8	31.6	322.2	64.4	5	49.1%	50.9%
16. West Bouldin Creek	WBO	4	200.0	50.0	23.1	5.8	223.1	55.8	7	70.3%	29.7%
17. Williamson Creek	WMS	6	199.0	33.2	94.3	15.7	293.3	48.9	8	66.9%	33.1%
Totals	sum	70									
	mean	4.1	156.0	38.5	61.8	14.2	217.9	52.7	9	69.8%	30.2%
	median	4	143.0	34.4	35.3	8.8	177.6	44.4	9	72.8%	27.2%
	max	6	289.9	72.5	214.9	44.0	358.5	82.2	17	97.7%	57.5%
	min	3	83.3	20.8	5.8	1.5	118.4	31.3	1	42.5%	2.3%

* Toxicity – Total Organic Carbon (TOC), Chemical Oxygen Demand (COD), Copper (Cu), Lead (Pb), and Zinc (Zn);
- Spills Risk (from the City's Spills Risk Index);
- Construction runoff loads score (provided by CRWR); and
- Future Reach Stability (from Chan and Associates erosion assessments (Chan & Associates, 1998)).

Also used, to a more limited extent, were State of Texas water quality assessment reports and data, data analyzed from the Environmental Resource Management Division's (ERM) water quality database, the Visual Index of Pollution for Town Lake, and impervious cover values.

2.2 SUPPORT INFORMATION FROM THE FLOOD PROBLEMS ASSESSMENT

The Integrated Solutions Development project team was provided flood problems information for both creek and storm sewer problem areas.

2.2.1 Support Information for Creek Flooding Problems

Assessment of existing creek flooding problems in the Phase I watersheds is based upon updated versions of hydrologic and hydraulic models developed over the years for each of the subject watersheds by the City of Austin, the Corps of Engineers, and a number of consultants. Given individual watershed and channel characteristics, the hydrologic models calculate design flow rates for varying storm event mean recurrence intervals (2-year, 25-year, 100-year, etc.). Using flow rate information developed from the hydrologic models, the hydraulic models calculate channel water surface elevations and flow velocities for the corresponding floods.

The City's hydrologic and hydraulic models database was originally developed in the 1980's and 1990's using a variety of hydrologic and hydraulic modeling packages including HEC-1, HEC-2, SCS TR-20, NUDALLAS, and the Austin Standard Method. In 1997, the Watershed Protection Department contracted with Loomis & Moore and several subconsultants to refine and update the existing hydrologic and hydraulic models database for the City's urban watersheds. During this initiative, urban watershed hydrologic models developed using the Austin Standard Method, NUDALLAS, or SCS TR-20 were translated to HEC-1. The City's hydraulic models developed using HEC-2 were translated to the Corps of Engineers' recently-developed HEC-RAS hydraulic modeling system. Documentation of the HEC-RAS and HEC-1 translations processes is presented in the document, "Flood Needs Assessment Models Study" (Loomis & Moore, 1997).

For the current project, the Watershed Protection Department, working in conjunction with consultants Camp, Dresser & McKee and Carter, Burgess developed a flood threat assessment procedure to define current flood problems. The flood threat assessment procedure utilizes water surface elevations and flow velocities derived from the HEC-RAS model translations to identify potentially flooded structures and calculate flow velocities for varying flood event mean recurrence intervals. Based upon flow velocities and the depth of flooding, public safety and property protection flood scores were calculated for individual structures and roadway crossings. For a given flood reach, the flood composite problem score is calculated with the following equations:

$$FC = [[S_{fps}/(S_{fps}+S_{fpp})]*FC_{ps}] + [[S_{fps}/(S_{fps}+S_{fpp})]*FC_{pp}]$$

where:

$S_{fps}/(S_{fps}+S_{fpp})$ = prioritization ratios defined from public opinion polling;
FC_{ps} and FC_{pp} = flood Problem Scores for public safety and property protection
fps = public safety for flooding; and
fpp = property protection for flooding

FC_{ps} and FC_{pp} are calculated using the following terms:

$$FC_{pp} = \tfrac{1}{2}(D_2)RV + 1/10(D_{10})RV + 1/25(D_{25})RV + 1/100(D_{100})RV; \text{ and}$$

$$FC_{ps} = \tfrac{1}{2}(D_2)(V_2)RV + 1/10(D_{10})(V_{10})RV + 1/25(D_{25})(V_{25})RV + 1/100(D_{100})(V_{100})RV$$

where:

RV = The sum of the resource values assigned to structures in the flood reach; and
V_2 = Flow velocity for the 2-year flood, etc.
D_2 = Flow depth for the 2-year flood, etc.

Resource values assigned to structures and roadways are as follows:

Structures

Property Protection Resource Values		Public Safety Resource Values	
Public Care Facilities	100	Public Care Facilities	100
Non-Residential Structure	80 garages?	Non-Residential Structure	40
Residential Multi-Family	60	Residential Multi-Family	80
Residential Single-Family	40	Residential Single-Family	60
Miscellaneous	10	Miscellaneous	10
Unclassified	0	Unclassified	0

Bridges

Property Protection Resource Values		Public Safety Resource Values	
Freeway	100	Freeway	100
Arterial	70	Arterial	80
Single Access	30	Single Access	60
Collector	20	Collector	20
Local	10	Local	40
Unclassified	0	Unclassified	0

Flood reach problem scores are developed for each flood reach stream segment. Flood reaches are defined at approximately 2,000-foot intervals along each creek. Table 2-3 presents a summary of flood reach problem scores by watershed. Appendix B-1 presents maps of flooded structures with degree of flooding for each of the 17 watersheds. Appendix D-1 presents plots of EII reach scores vs. creek station for Water Quality, Flood, Erosion, and Integrated (Weighted and Combined) Scores.

2.2.2 Support Information for Storm Sewers Problem Areas

For storm sewers, the Stormwater Management Division provided the project team with a listing of 17 problem areas for which rehabilitation would be accomplished through the CIP program. These projects are documented in Section 4.2.2 ("Protocol for Storm Sewer Flood Projects Identification").

2.3 SUPPORT INFORMATION FROM THE EROSION PROBLEMS ASSESSMENT

Raymond Chan and Associates, Inc. performed watershed erosion assessments on the 17 Phase I watersheds. The primary components of the 17 individual studies were:

- Stream Inventory of 170 miles of streams to identify existing and future erosion problems;
- Classification of erosion problems to assist in prioritizing and construction planning;
- Classification of 199 like reaches (the "erosion reaches") as alluvial, rock bed, rock channel or, structurally controlled;
- Use of a rapid geomorphic assessment form to determine current channel stability;
- Geomorphic survey of 60 stream sites to develop channel enlargement relationships;
- Application of channel enlargement curves to estimate future channel erosion, bank loss, and sediment transport;
- Development and application of a prioritization system to rank erosion problem severity by like reaches; and,
- General recommendations to manage channel erosion on a local, inter-reach, and watershed basis.

The findings of the study are summarized as follows:

- 13 Type 1 erosion problems (primary structures or roads currently threatened);
- 473 Type 2 erosion problems (walls, fences, trees, utility lines, yards, recreation currently threatened);
- 420 Type 3 erosion problems (all resources not currently threatened but which may be in the future given current trends); and
- 47 of 199 like reaches are classified as "unstable" channel reaches (meaning that they will continue to erode, adjust, and widen to accommodate greater storm flows due to urbanization).

This data was input along with other supporting information to develop an erosion reach problem score for each erosion reach. Erosion reach problem scores are derived from composited erosion problem values for each of the four problem types: (1) Type 1 problems; (2) Type 2 problems; (3) Type 3 problems; and (4) future reach stability threat.

For each problem type, problem scores are based on the following problem element weightings:

Type 1 Problems

Percent Current vs. Future		*Subcomponent Percentages*	
75%	Current Problem Severity	20%	Geotechnical
		50%	Imminent Threat
		10%	Site Geomorphology
		20%	Current Reach Stability
25%	Future Reach Stability		

Type 2 Site Problems on Private Property

Percent Current vs. Future		*Subcomponent Percentages*	
75%	Current Problem Severity	50%	Site Geomorphology
		75%	Meander Factor
		25%	Knickpoint Factor
		50%	Reach Stability
25%	Future Reach Stability Score		

Type 2 Site Problems on Public Lands (including Parkland, Priority Woodlands, and Hike & Bike Trails)

Resource Values weightings for public land types:

50	Public Parkland >=500 LF
40	Public Parkland <500 LF
60	Priority Woodland (public)
35	Priority Woodland (private)
50	Hike and Bike Trail

Percent Current vs. Future		*Subcomponent Decision Variables*
75%	Current Problem Severity	Magnitude of Problem
		No. of Excessive Meanders
		No. of Bends >= 60°
		Current Reach Stability
25%	Future Problem Severity	

The total Type 2 Score is the sum of the private and public land scores.

Type 3 Site Problems on Private Lands (future only)

Percent Problem Elements		*Subcomponent Percentages*	
50%	Site Geomorphology	75%	Meander Factor
		25%	Knickpoint Factor
50%	Future Reach Stability		

Type 3 Site Problems on Public Lands (future only)

Percent Problem Elements

30%	Excessive Meander location Score
15%	Bend >= 60o Location Score
55%	Future Reach Stability Score

Future Reach Stability Problems

Percent Problem Elements

25%	Delta ER [enlargement ratio]
25%	Percent Future Adjustment
10%	Qs/L (sediment quantity per unit length)
25%	Delta QDOM [future change in the channel-forming flow rate]
10%	Meanders
5%	Knickpoints

Scores derived using the above criteria allow the comparison and prioritization of erosion reaches. This information is used to facilitate the decision-making process for determination of high priority project locations and potential approaches to managing channel erosion. Specific scoring methodologies are presented in the document, "Technical Procedures for the Watershed Erosion Assessments" (Raymond Chan and Associates, Inc., September 1997). Complete documentation of scoring is presented in the 17 individual *Watershed Erosion Assessment* reports (Raymond Chan and Associates, Inc., 1998).

Table 2-4 presents a summary of erosion problem scores by watershed. Appendix D-1 presents plots of EII reach scores vs. creek station for Water Quality, Flood, Erosion, and Integrated (Weighted and Combined) Scores.

2.4 INTEGRATED PROBLEM SCORES

In order to identify the best opportunities for integrated solutions application, the City developed a combined problem scoring system which integrates the flood, water quality, and erosion problem scores. The integrated problem scores were developed by Camp, Dresser & McKee combining the individual problem reach segments for the three missions to derive a single, integrated problem score. The union of separate water quality (EII), flood, and erosion reaches yielded a series of smaller (integrated) stream segments each with unique values for the three problem scores.

For each integrated reach, the final, combined reach problem scores are developed from a weighted summation of the individual reach problem scores. Weightings were derived from public opinion surveying of Austin's citizens in each watershed. The surveys recorded citizen's priorities with respect to the importance of each of the three missions. Table 2-5 summarizes the findings of the citizen's survey for each of the 17 Phase I watersheds.

The integrated problem scores for each watershed are summarized in Table 2-6a and Table 2-6b. Table 2-6a calculates the scores weighted by the length of stream reach (a long stream reach will receive a proportionately greater score in calculating the watershed total than a shorter reach). Table 2-6b calculates the score unweighted by reach length (each reach is given equal weighting, regardless of its size). This method accounts for the fact that most reaches were established to reflect the uniformity of a channel type, not as an indication of problem severity. Therefore, a short reach may have important problems which can be ignored when weighing solely by reach length. Appendix D-1 presents plots of EII reach

Table 2-4: Summary of Erosion Reach Problem Scores by Watershed

Watershed	Abbrev.	Drainage Area (ac)	Geomorphic Reaches	$(E_R)_{EX\text{-}CUR}$	$(E_R)_{FUT\text{-}ULT}$	Ratio of Ratios	Qs/L (tons/ft)	Problem Scores						
								Type 1 Sites*	Type 2 Sites*	Type 3 Sites*	Future Reach Stability*	Overall Totals*	Overall Totals per Reach	Wshed Rank
1. Barton Creek	BAR	76,700	10	1.00	1.05	1.05	0.75	-	27.8	11.0	76.0	44.3	4.4	16.0
2. Blunn Creek	BLU	880	5	6.28	8.51	1.36	1.34	-	56.8	79.8	179.2	120.0	24.0	11.0
3. Boggy Creek	BMK	960	5	5.91	6.85	1.16	1.27	-	82.0	43.7	66.8	77.5	15.5	14.0
4. Bull Creek	BOG	8,360	7	4.92	5.38	1.09	1.02	72.7	153.2	169.1	95.7	212.2	30.3	9.0
5. Buttermilk Creek	BUL	19,350	21	1.05	1.49	1.41	2.57	100.0	100.8	260.3	493.8	383.6	18.3	3.0
6. Country Club Creek	CNT	1,700	8	1.81	4.15	2.29	3.75	100.0	134.3	176.7	429.4	345.1	43.1	4.0
7. East Bouldin Creek	EBO	930	4	5.35	6.34	1.19	1.40	100.0	116.9	159.6	64.5	198.2	49.6	10.0
8. Fort Branch	FOR	2,110	10	4.78	5.92	1.24	1.35	100.0	187.1	196.2	182.2	286.3	28.6	5.0
9. Harper's Branch	HRP	340	6	5.26	5.60	1.06	0.19	-	27.4	17.4	28.6	29.2	4.9	17.0
10. Johnson Creek	JOH	1,040	10	5.46	5.70	1.04	0.17	-	73.7	21.5	42.8	56.9	5.7	15.0
11. Little Walnut Creek	LWA	8,360	17	4.40	5.29	1.20	3.02	100.0	115.2	80.2	289.1	250.3	14.7	7.0
12. Shoal Creek	SHL	8,260	18	5.14	5.84	1.14	1.27	100.0	145.7	177.0	243.3	273.3	15.2	6.0
13. Tannehill Branch	TAN	2,560	8	5.53	5.88	1.06	0.48	200.0	103.1	51.9	66.3	212.2	26.5	8.0
14. Waller Creek	WBO	6,480	5	5.26	5.58	1.06	0.68	100.0	27.4	52.4	35.6	108.1	21.6	13.0
15. Walnut Creek	WLN	36,130	34	1.14	4.37	3.84	61.33	200.0	938.7	1,163.2	2,563.1	1,758.3	51.7	1.0
16. West Bouldin Creek	WLR	3,620	12	5.57	6.01	1.08	0.49	-	155.4	23.5	109.0	118.8	9.9	12.0
17. Williamson Creek	WMS	19,260	19	1.15	1.70	1.48	1.77	-	353.2	357.4	441.9	451.2	23.7	2.0
Totals	sum	197,040	199											
	mean	11,591	12	4.12	5.04	1.40	4.87	69.0	164.6	178.9	318.1	289.7	22.8	9.0
	median	3,620	10	5.14	5.60	1.16	1.27	100.0	115.2	80.2	109.0	212.2	21.6	9.0
	max	76,700	34	6.28	8.51	3.84	61.33	200.0	938.7	1,163.2	2,563.1	1,758.3	51.7	17.0
	min	340	4	1.00	1.05	1.04	0.17	-	27.4	11.0	28.6	29.2	4.4	1.0

* Key to Scoring Categories:

Type 1 Sites:	primary structures or roads currently threatened.
Type 2 Sites:	walls, fences, trees, utility lines, yards, parks and recreational facilities currently threatened.
Type 3 Sites:	all Type 1 and Type 2 resources not currently threatened but which may be in the future.
Future Reach Stability:	a measure of creek physical stability inlcuding predicted future enlargement, sediment load, dangerous meanders, and knick points.

Table 2-5: Summary of Citizen Preferences for Prioritizing Water Quality, Flood, and Erosion Control Concerns by Watershed

Watershed	Abbrev.	Percentage of Priority			
		Water Quality	Flood	Erosion	Totals
1. Barton Creek	BAR	41.2%	28.3%	30.5%	100.0%
2. Blunn Creek	BLU	40.4%	26.9%	32.6%	100.0%
3. Boggy Creek	BOG	39.7%	29.9%	30.4%	100.0%
4. Bull Creek	BUL	39.6%	31.8%	28.6%	100.0%
5. Buttermilk Creek	BMK	39.6%	30.7%	29.7%	100.0%
6. Country Club Creek	CNT	41.5%	30.3%	28.2%	100.0%
7. East Bouldin Creek	EBO	39.5%	28.7%	31.7%	100.0%
8. Fort Branch	FOR	35.1%	32.0%	32.9%	100.0%
9. Harper's Branch	HRP	39.0%	28.9%	32.1%	100.0%
10. Johnson Creek	JOH	38.6%	30.3%	31.0%	100.0%
11. Little Walnut Creek	LWA	40.1%	29.8%	30.1%	100.0%
12. Shoal Creek	SHL	39.0%	30.5%	30.5%	100.0%
13. Tannehill Branch	TAN	36.3%	33.5%	30.3%	100.0%
14. Waller Creek	WLR	41.8%	30.1%	28.1%	100.0%
15. Walnut Creek	WLN	38.2%	31.1%	30.6%	100.0%
16. West Bouldin Creek	WBO	40.7%	29.2%	30.1%	100.0%
17. Williamson Creek	WMS	41.0%	30.2%	28.8%	100.0%
Totals	mean	39.5%	30.1%	30.4%	100.0%
	median	39.6%	30.2%	30.4%	
	max	41.8%	33.5%	32.9%	
	min	35.1%	26.9%	28.1%	
	stdev	1.8%	1.5%	1.4%	

Table 2-6a: Summary of Water Quality, Flood, Erosion, and Integrated Problem Scores by Watershed Weighted by Stream Length

Watershed	Abbrev.	Total Stream Length (ft.)	Problem Score*				Rank, Integrated Score
			Water Quality	Flood	Erosion	Integrated Score	
1. Barton Creek	BAR	264,275	78.5	0.0	4.1	39.2	5
2. Blunn Creek	BLU	12,850	28.7	1.1	35.6	27.7	11
3. Boggy Creek	BOG	36,660	32.7	2.8	39.5	30.0	10
4. Bull Creek	BUL	125,855	78.9	1.4	28.0	47.2	2
5. Buttermilk Creek	BMK	12,265	26.0	0.1	28.0	21.9	13
6. Country Club Creek	CNT	48,070	41.2	2.0	64.9	41.9	4
7. East Bouldin Creek	EBO	17,957	46.7	1.8	70.2	48.3	1
8. Fort Branch	FOR	33,160	30.1	5.2	48.2	33.0	8
9. Harper's Branch	HRP	6,150	35.1	0.0	8.8	19.4	16
10. Johnson Creek	JOH	16,895	68.1	0.1	12.8	36.0	6
11. Little Walnut Creek	LWA	84,305	21.6	3.1	21.3	18.7	17
12. Shoal Creek	SHL	64,041	29.7	2.9	26.0	24.1	12
13. Tannehill Branch	TAN	47,387	20.1	0.5	29.5	19.5	15
14. Waller Creek	WLR	39,584	28.8	1.9	14.9	19.7	14
15. Walnut Creek	WLN	295,835	43.9	1.9	68.4	45.1	3
16. West Bouldin Creek	WBO	22,661	48.2	2.7	18.9	31.0	9
17. Williamson Creek	WMS	176,583	49.0	3.7	30.0	35.2	7
Totals	sum	1,304,533					
	mean	76,737	41.6	1.8	32.3	31.6	9
	median	39,584	35.1	1.9	28.0	31.0	9
	max	295,835	78.9	5.2	70.2	48.3	17
	min	6,150	20.1	0.0	4.1	18.7	1
	stdev	88,574	18.4	1.5	20.2	10.2	5

* All problem scores are the sum of the individual problem scores for stream reaches within a watershed divided by the total stream length of the watershed, thereby yielding a weighted average score.

Table 2-6b: Summary of Water Quality, Flood, Erosion, and Integrated Problem Scores by Watershed Weighted by Number of Composite Reaches

Watershed	Abbrev.	Total No. of Composite Reaches	Problem Score*				Rank, Integrated Score
			Water Quality	Flood	Erosion	Integrated Score	
1. Barton Creek	BAR	17	53.2	0.0	5.5	27.7	11
2. Blunn Creek	BLU	16	32.3	1.1	34.9	29.2	10
3. Boggy Creek	BOG	31	32.7	2.8	39.7	30.0	9
4. Bull Creek	BUL	91	77.6	1.7	24.9	45.8	2
5. Buttermilk Creek	BMK	13	26.8	0.1	27.4	22.1	13
6. Country Club Creek	CNT	36	44.0	1.2	63.4	42.4	4
7. East Bouldin Creek	EBO	18	44.4	1.5	72.5	48.0	1
8. Fort Branch	FOR	22	30.1	4.7	47.3	32.5	8
9. Harper's Branch	HRP	11	39.4	0.0	8.1	21.1	14
10. Johnson Creek	JOH	21	66.4	0.1	11.3	34.7	6
11. Little Walnut Creek	LWA	65	22.5	3.1	20.4	18.8	17
12. Shoal Creek	SHL	56	30.0	1.9	22.5	22.7	12
13. Tannehill Branch	TAN	35	21.3	0.5	31.6	20.8	15
14. Waller Creek	WLR	36	28.8	1.8	15.1	19.8	16
15. Walnut Creek	WLN	181	42.5	1.7	66.6	43.7	3
16. West Bouldin Creek	WBO	21	48.7	2.8	22.0	32.5	7
17. Williamson Creek	WMS	111	48.9	4.6	29.9	35.4	5
Totals	sum	781					
	mean	46	40.6	1.7	31.9	31.0	9
	median	31	39.4	1.7	27.4	30.0	9
	max	181	77.6	4.7	72.5	48.0	17
	min	11	21.3	0.0	5.5	18.8	1
	stdev	45	15.3	1.5	20.2	9.6	5

* All problem scores are the sum of the individual problem scores for stream reaches within a watershed divided by the number of reaches in each the watershed, thereby yielding a weighted average score.

scores vs. creek station for Water Quality, Flood, Erosion, and Integrated (Weighted and Combined) Scores.

3.0 INVENTORY OF STORMWATER MANAGEMENT PRACTICES

The foundation of the Integrated Solutions Development procedure begins with compilation of this *Solutions Inventory* in which the basic characteristics of all available capital project technologies, regulations, and operating programs are defined. This body of information is intended to represent the "state of the art" with respect to individual solution effectiveness, benefits, constraints, and applicability. This information serves in the current context to support preliminary and final project selection procedures but does not necessarily contain all information utilized to make solutions selection decisions in the Integrated Solutions Development process.

The solutions descriptions presented in this section are general in nature and intended to provide useful information regarding the character of the full range of solution types. Some of the information presented herein results from direct engineering experience and judgment. However, most was derived from multiple technical sources including: (1) The Town Lake Report; (2) multiple publications by Tom Schueler; and (3) LCRA's Draft Document, "Highland Lakes Nonpoint Source Pollution Control Ordinance Technical Manual (Loomis & Moore, 1996)

3.1 WATER QUALITY CONTROLS

3.1.1 Source Controls

A. Inlet Filters

Description

Stormwater inlet filters are perforated sheet metal inserts placed inside storm sewer inlets to trap trash and other generally large-scale pollutants. Figure 3-1 illustrates the inlet filter design used by the City of Austin. It is constructed of light weight aluminum and mounted inside the inlet on angled supports. Stormwater inlet filters collect trash, debris, and sediment transported by stormwater runoff into storm sewer inlets. As a layer of coarse sediment accumulates on the filters, finer grain sediments are also potentially trapped.

Applicability

Inlet filters are typically retrofit into existing storm sewer inlets. They are best applied in areas with the following characteristics:

1. A high degree of urbanization;
2. Significant automobile traffic;
3. Pedestrian/motorist activity likely to result in significant trash accumulation; and
4. High density development making major structural retrofits impractical.

Inlet filters can be used as pre-treatment devices to prevent clogging or debris accumulation in other downstream control measures, such as infiltration basins. Inlet filters are generally not well-suited for use in single family residential areas except in areas with high pedestrian activity.

Effectiveness/Advantages

- A preliminary study by the COA Drainage Utility shows that inlet filters have functioned very effectively in trapping trash and less effectively in capturing sediments.
- This technology has been seen in Austin to collect large amounts of trash and debris, especially during periods of high pedestrian activity in the downtown area.
- Filter removal and maintenance is a relatively efficient procedure.

Constraints

- Since most of the total sediment load comes from channel erosion, this alternative will have limited impact upon sediment reduction goals. Inlet filters are ineffective in capturing dissolved pollutants and constituents associated with finer grain sediment.
- Inlet filters must be frequently maintained to maximize performance and to prevent excessive trash accumulation and impaired functionality as a drainage structure.

Operations and Maintenance

The Department of Public Works recommends at least quarterly maintenance of inlet filters. In areas high in pedestrian traffic (the Sixth Street entertainment district, for example), maintenance is routinely undertaken almost once per week. Maintenance costs include labor, truck usage/maintenance, initial truck purchase, and administrative support for the maintenance program. Maintenance costs are estimated to range from $100/year/inlet for inlets maintained quarterly to $500/year/inlet assuming 40 maintenance visits a year.

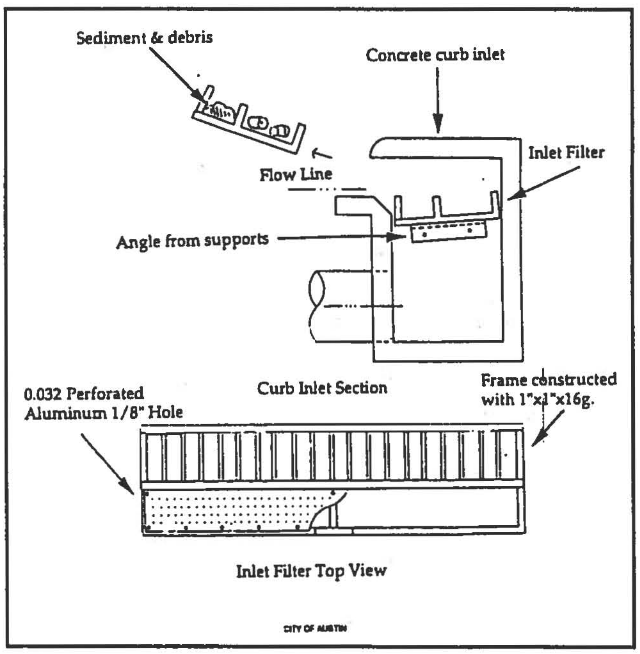


Figure 3-1. Inlet filter schematic *Source: City of Austin*

B. Trash and Debris Booms

Description

Trash and debris booms are essentially modified oil spill containment booms placed across urban creeks (generally near the confluence with a downstream river or lake) to catch floatable trash and organic debris. Booms are secured at the mouths of major feeder creeks such that mid-stream velocity is dissipated and the booms are not destroyed by the full-force of high velocity creek flows. By capturing floatable trash and woody-organic debris, booms target the most obvious, visual signs of nonpoint source pollution. Figure 3-2a presents a plan view of a typical trash and debris boom configuration. Figure 3-2b presents a cross-section view of a trash and debris boom.

Applicability

Trash and debris booms are principally used for trash removal at the confluence of major feeder creeks with receiving waters. Smaller scale applications may be possible upstream, but may not justify the necessary maintenance requirements. Booms have been installed at Shoal, West Bouldin, and Waller Creeks along Town Lake.

Effectiveness/Advantages

- Trash and debris booms can effectively accumulate litter at a single location preventing scattering of floatable trash and debris into receiving waters along inaccessible shoreline areas where cleanup efforts are difficult.
- Booms work best with low to moderate storm flows; high flows can cause boom failure and release of captured debris.

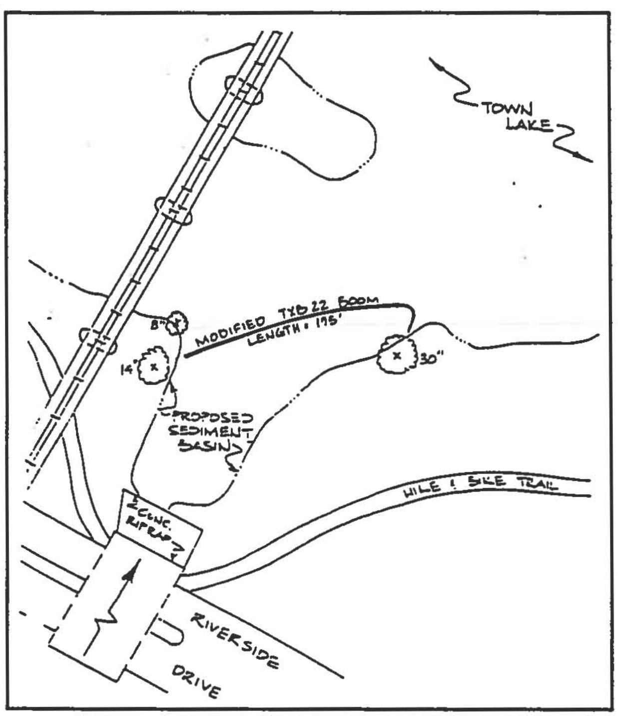


Figure 3-2a. Trash boom *Source: City of Austin*

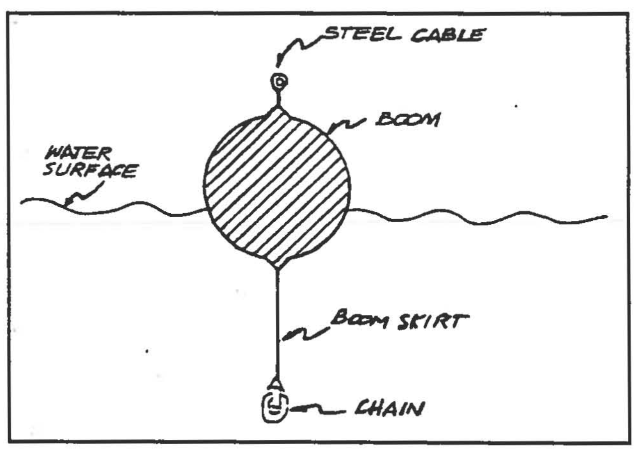


Figure 3-2b. Trash boom *Source: City of Austin*

- While primarily a trash reduction BMP, booms can also remove organic debris and may have some indirect impact on removing nutrients and long term benthic oxygen demand.
- The Waller Creek boom traps an average of 65 gallons of trash and debris per storm event. The boom at West Bouldin Creek trapped 102 thirty gallon bags of trash and debris in a single event.
- Cleanups can be monitored for the quantity and character of trash and debris trapped. This information may then be used to target upstream sources of trash for education or regulation.

Constraints

- Trash and debris accumulations can escape boom containment by: (1) being pushed over the top of the boom; (2) passing through areas where the skirt of the boom does not hang to its full depth due to rocks or other objects under the surface; (3) being pushed back upstream by the wind; or (4) when the boom is torn loose by heavy debris caught during high velocity, high water level conditions.
- Replacement costs for lost booms is relatively high (approximately $2,500).
- Aesthetic concerns are significant since the booms are frequently considered unnatural eyesores.
- There is often a lack of suitable sites for boom location. For example, a boom at the mouth of Barton Creek would be impractical, because canoes must be able to navigate back and forth from Town Lake. On East Bouldin Creek, there is inadequate energy dissipation to sustain a boom.
- Although the trash and debris booms have been effective at decreasing trash inputs to Town Lake, the City of Austin predicts that this alternative would achieve only about a 10% overall reduction in trash inputs.

Operations and Maintenance

Debris accumulation behind booms should be cleaned immediately after storm events. Clean-ups usually are completed in about two hours per boom. Volunteer groups, including scouting organizations, citizen water quality monitors, and neighborhood "adopt a stream" groups can be recruited as maintenance personnel.

C. Retrofitting of Existing Stormwater Management Ponds for Trash Removal

Description

This technology is generally applied as an added nonpoint source (NPS) control feature in conjunction with the primary water quality purposes of structural water quality controls. Retrofitting of existing stormwater management ponds generally involves placement of a screening device to assure that trash and debris is captured and stored in the structural control. Many water quality and flood control ponds are not designed specifically to detain trash, thus this approach may be most applicable in the context of a retrofit program.

Applicability

Water quality and flood control ponds are logical points at which to collect trash and other floatable stormwater debris. This approach requires corresponding trash removal and enforcement programs.

Effectiveness/Advantages

- If properly fit with trash screening devices, stormwater ponds are highly effective measures for capturing and accumulating trash and debris.

Constraints

- Significant trash accumulation may impact the intended flow characteristics of the outflow structure. The design of the trash screen must not impair the original function of the facility.
- Most water quality ponds are already effective in removing trash. The marginal benefit of trash screen retrofitting may be minimal.
- Only the portion of storm flow which enters the pond will be treated, although the treated portion does generally contain the relatively more trash-laden first flush.

Operations and Maintenance

Trash and debris removal are routine components of structural water quality control maintenance programs. Trash removal may have to occur more frequently for ponds retrofit with trash screens.

D. Impervious Cover Removal

Description

Impervious cover removal is the removal and replacement of impervious surfaces with stabilized, vegetated pervious cover to reduce runoff and increase infiltration. This approach can be used where impervious cover is over-built for its intended purpose or has become obsolete due to site abandonment.

Applicability

Impervious cover removal is theoretically possible throughout urbanized areas of the City. Application of this approach would best be implemented as a City-wide program. Example applications include narrowing of lightly trafficked roadways and removal of unused parking lot pavement, replacing it either with pervious landscaped areas or pervious pavements (see "Porous Pavement" below).

Effectiveness/Advantages

- Impervious cover reduction provides an effective, passive means of curtailing existing water quality, erosion and flood threats by reducing runoff and increasing infiltration.

Constraints

- The cost for impervious cover removal (excavation, revegetation, and loss of function) may be considered to exceed the marginal benefit.
- Practical and functional considerations associated with the use and purpose of the impervious cover may generate public opposition to its removal.
- Except where the City has direct control over properties, this retrofit BMP can only be used on a volunteer basis by land owners who recognize the advantage and benefit of doing so. Some City incentive may be offered to increase the participation rate.
- Existing COA parking and roadway regulations may have to be reconsidered to promote significant application of this approach.

Operations and Maintenance

Removal of impervious cover improves water quality via passive mechanisms requiring little or no maintenance. This is a significant advantage of this BMP. However, over the long term, developed properties tend to add, not remove, impervious cover, and gains made through removal can be later lost. For sustainability, the implementation of this technique may have to be combined with public education.

E. Impervious Cover Disconnection

Description

Disconnection of impervious cover is a retrofit technique which removes the direct hydraulic link between impervious cover and waterways. This practice operates on the principle that the negative impacts of impervious cover on water quality and quantity can be reduced if runoff from these areas is redirected over pervious areas for possible storage, energy dissipation, and infiltration. Conventional site designs encourage water to exit as rapidly as possible via impervious conveyance paths (storm drains, storm sewers, concrete-lined channels, etc.). This technique allows rooftop, roadway, and parking lot runoff to drain across landscaped or other pervious areas prior to entry into waterways.

Applicability

Impervious cover disconnection is possible if: (1) imperious cover is currently connected via impervious conveyance paths to waterways and (2) there is sufficient pervious area over which to direct the water. Field studies have shown impervious cover disconnection can significantly affect the amount of runoff generated in developed areas. A Birmingham, Alabama study used extensive monitoring and modeling to show that appreciable reductions in Rv could be achieved through such disconnections. The benefits are generally proportional to the area not currently connected. A reduction of 7% in the runoff coefficient (Rv) was estimated to be possible through roof drainage disconnections in an area with 70% of the residences already disconnected. The price for disconnections was nominal ($125 per household) and, in terms of cost-effectiveness, this practice was found to outperform structural pond BMP measures analyzed in the same study (Pitt and Voorhees, 1993).

Effectiveness/Advantages

- If disconnection is possible and adequate pervious, well-drained area exists, this practice represents an effective means of improving water quality and reducing flood and erosion problems.
- Disconnection costs are generally low compared with the construction of engineered vegetative BMPs.

Constraints

- Impervious cover may already be disconnected in residential areas. An attempt to identify opportunities to disconnect impervious cover in the Hyde Park neighborhood revealed that less than 5% of the buildings had direct roof connections to roads and storm sewer drainage systems (Loomis & Associates, 1996).

- Most commercial and multifamily areas lack sufficient pervious areas for disconnection.
- Rooftops, the most easily disconnected areas, have relatively clean runoff.

Operations and Maintenance

Impervious cover disconnection improves water quality via passive mechanisms requiring little or no maintenance. This is a significant advantage of this BMP. However, over the long term, developed properties tend to add, not remove, impervious cover, and gains made through disconnection can be later lost. For sustainability, this technique should be combined with public education.

F. Bioretention

Bioretention is a water quality practice using shallow storage of stormwater runoff in a depressed, vegetated area. Figure 3-3 shows plan and profile schematics of a bioretention facility. Pollutants are removed by physical and biological processes associated with vegetation and soils. The soil in the storage area is selected or conditioned to promote infiltration. Facilities typically are designed to contain the first flush of the impervious portion of the site; maximum water depths are typically shallow (less than one foot). Runoff is generally designed to enter the system via sheet flow over a grassed filter strip, providing pretreatment to limit clogging of infiltrative areas (Engineering Technologies Associates, 1993; LCRA, 1996).

The use of vegetation in this system is modeled after the properties of a terrestrial forest ecosystem; best designs therefore include a mature canopy and understory of trees, a shrub layer, and an herbaceous layer.

Bioretention may be accomplished by constructing an area with sand infiltration and/or thick layer of backfilled planting soil beneath planted vegetation or by using existing, dense vegetation over relatively deep and pervious soil (LCRA, 1996).

Applicability

Bioretention is typically used to treat urban areas or roadways with relatively high impervious cover, although it can be used to improve stormwater from a variety of land uses. Storage is usually placed offline to avoid erosion during large storm events. Online facilities are feasible if the mean flow velocity during the 6-month storm does not exceed about 3 feet per second. Use of bioretention is usually limited to small drainage areas up to an acre in size (LCRA, 1996).

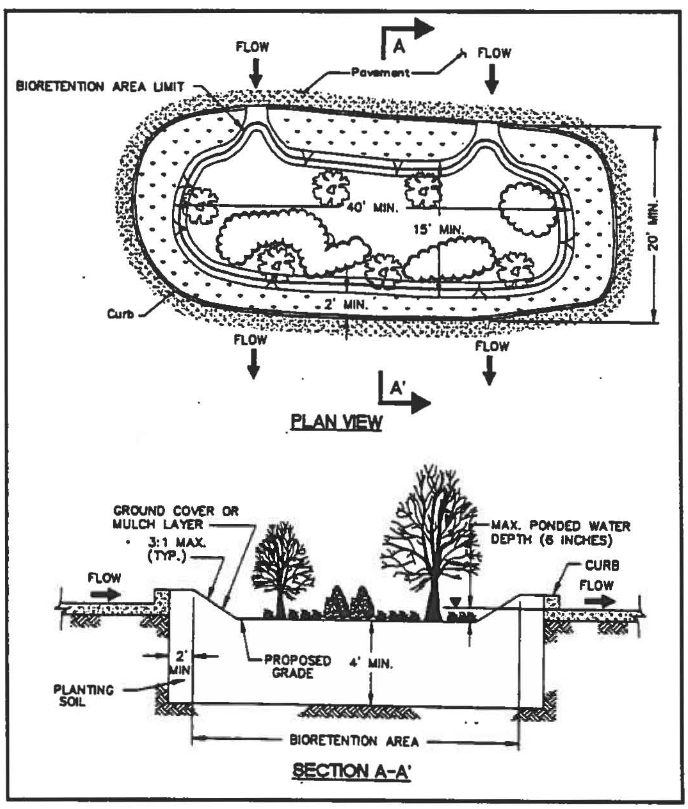


Figure 3-3. Bioretention facility *Source: City of Austin*

Experience in Maryland with bioretention has shown that substantial savings in storm drain construction costs can be realized using bioretention strategies. While this approach may not be applicable as a widespread urban retrofit policy, cost savings may be justified in cases where existing storm drainage is inadequate or in disrepair.

Effectiveness/Advantages

- If properly designed and constructed, bioretention is a passive, effective, sustainable, and aesthetically pleasing water quality control technique.
- Pollutant removal efficiencies for adequately-sized bioretention facilities are estimated to be high for this "no-discharge" approach: 80% for TSS, 75% for TP and 75% for total petroleum hydrocarbons (LCRA, 1996).
- Bioretention can aid in reducing peak flood flows by providing runoff storage.

Constraints

- Bioretention facilities, like most pond BMPs, are most easily installed prior to full urban build-out. Sufficient space may not be available in urbanized areas.
- Proper plant selection and soils are both critical to the success of this technology. Careful facility design is necessary to limit clogging and to sustain healthy vegetation.
- If poor drained, these facilities can serve as pest breeding areas.

Operations and Maintenance

Maintenance requirements include inspections, remulching bare areas, trash removal, removing and replacing dead and diseased vegetation, and removing sediment when the depth reaches 3 inches or interferes with vegetation health (LCRA 1996). Regular maintenance is critical, especially during establishment of vegetation.

G. Infiltration Basins

Description

Infiltration basins are holding basins designed to capture runoff and allow it to infiltrate directly to the soil profile rather than discharging overland to receiving waters. Figure 3-4 shows a schematic infiltration basin design. As water migrates through porous soil and rock, pollutant attenuation mechanisms include precipitation, sorption, physical filtration, and bacterial degradation. This BMP type is intended to mimic the natural water retaining and infiltration characteristics of undeveloped watersheds. Basins can be dug from native alluvial soils, built with structural walls, or created with berms. Typical designs allow for complete basin draining to occur within 2 to 3 days.

Applicability

The use of infiltration basins is restricted by numerous site factors including soils, slope, water table and contributing watershed area. Contributing watershed areas are generally recommended not to exceed 2 and 15 acres (Schueler et al., 1992). Infiltration basins are not feasible if the contributing watershed has a slope of greater than 20%; less than 5% is preferable. The seasonally high water table should be a minimum of 2-4 feet below the floor of the basin (Schueler, 1987). Field-tested soil infiltration rates should be at least 0.5 inches/hour and soils should not have greater than 30% clay content (class "D" hydrologic type soils) (Schueler, 1987).

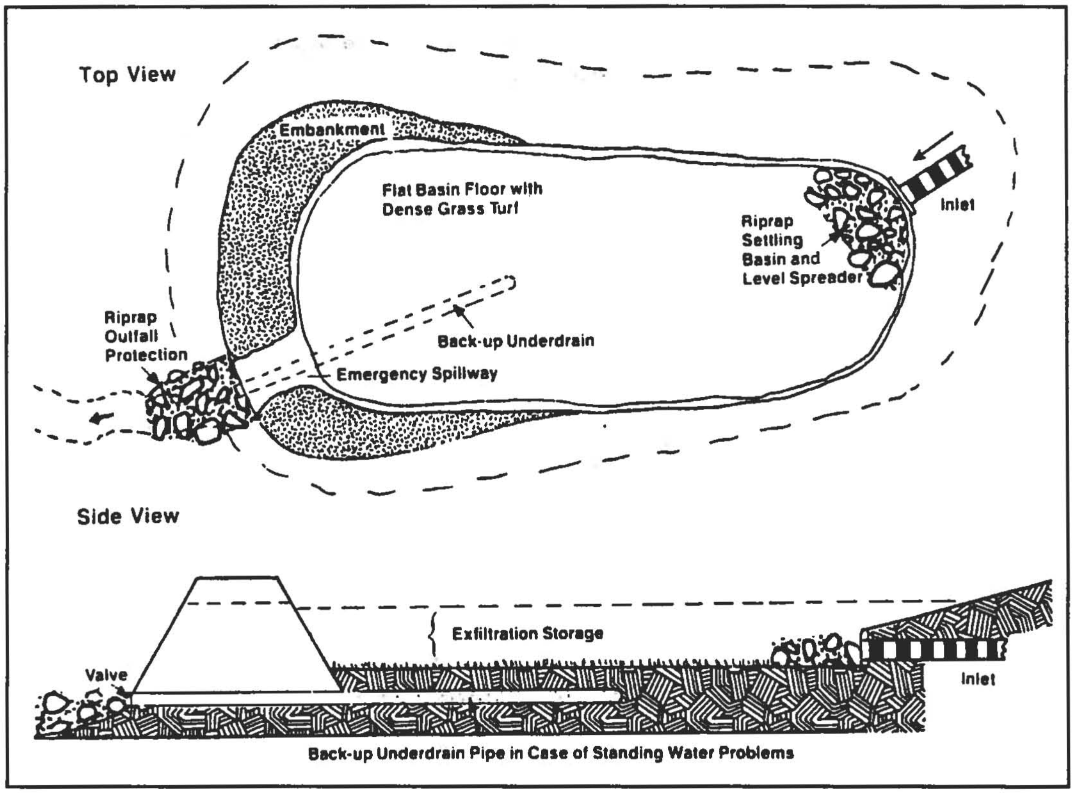


Figure 3-4. Schematic design of an infiltration basin *Source: Schueler, 1987*

In the Austin area, most soils are shallow with hard underlying bedrock and have high clay content with infiltration rates less than 0.2 inches per hour, unsuitable for infiltration basins. Some local geologic formations, such as the Colorado River terrace deposits and alluvium, have favorable infiltration properties; however, these formations are not widely distributed across the city. The Edwards limestone, a formation common to west Austin, can have extremely high permeability, but is not generally suitable for infiltration measures because its karst nature provides large openings with little filtration value. Use of infiltration measures in the Barton Springs Zone would require additional pre-treatment with structural and vegetative controls. A small area of the Edwards Aquifer north of the river could be used for infiltration, especially to restore base flow to Shoal Creek.

Effectiveness/Advantages

- The principal benefit of infiltration basins is the approximation of pre-development hydrology: runoff is infiltrated and evaporated rather than flushing directly to creeks during storm events. Infiltration basins can be useful for reducing peak flows and decreasing downstream channel erosion. Enhanced designs use sand filtration prior to infiltration to increase pollutant removal and limit facility clogging.
- If functioning properly, this approach is presumed to have high removal efficiencies for particulate pollutants and moderate removal of soluble pollutants. Actual pollutant removal would be expected to vary due to differing soil types from site to site. Removal rates have been estimated to range as follows: 75-99% for sediment, 50-75% for total phosphorus, 45-70% for total nitrogen, 70-90% for BOD and 75-98% for bacteria (Schueler, 1987).

Constraints

- In practice, infiltration basins are relatively short-lived systems, principally due to clogging. Between 60% and 100% of basins studied were not capable of infiltrating runoff after 5 years (Schueler et al., 1992).
- Many soil and bedrock types are not suitable for infiltration basins due to low porosity and permeability. This is especially true in portions of the Austin area which feature tight clay soils. Limitations on sufficient open space for construction is a related constraint. Basins may not be placed in areas with locally high water tables.
- Infiltration basins offer the potential for build-up of dissolved salts and toxics. Over time, the infiltration of polluted stormwater may accumulate constituents that can adversely effect vegetation and pollute groundwater (Schueler, 1987).
- These systems must be continuously maintained to avoid clogging and failure.

Operations and Maintenance

Basin maintenance requirements include inspections, mowing, debris and litter removal and, at a lesser frequency, tilling, revegetation and sediment removal. Removal of coarser sediment in a settling chamber prior to entering the infiltration basin helps prevent clogging. However, in practice, even regular maintenance has not proven sufficient to prevent clogging of infiltration basins. Clogged basins are very difficult to restore and many have been converted to wet ponds or wetlands.

H. INFILTRATION TRENCHES

Description

Infiltration trenches are shallow (3-8 feet deep) excavated trenches backfilled with stone to create an underground stormwater storage reservoir. Runoff either enters directly at the surface or flows into underground trenches through a pipe drainage system. Figure 3-5 shows a diagram of an infiltration trench. Captured runoff either infiltrates into the adjacent subsoil or is collected by perforated pipes and routed to an outflow facility. Surface runoff flows directed to an infiltration basin are typically filtered through a grass buffer to limit clogging.

Applicability

Infiltration trenches are generally used only with small drainage areas including: (1) for capture of surface runoff in highway median strips; (2) at the perimeter of parking lots; or (3) in conjunction with swale systems for low density residential runoff. Like infiltration basins, application of infiltration trenches is restricted by soils, water table, and slope and contributing area conditions. Infiltration trenches are useful only in areas with permeable soils. Field-tested soil infiltration rates should be at least 0.5 inches/hour and soils should not have greater than 30% clay content (class "D" hydrologic type soils). Underground trenches should not be used on sites with slopes greater than 20% and surface trenches are not recommended when slopes are greater than 5%. Trenches need to be constructed at least 4 feet above bedrock and 2 to 4 feet above the seasonally high water table (Schueler, 1987).

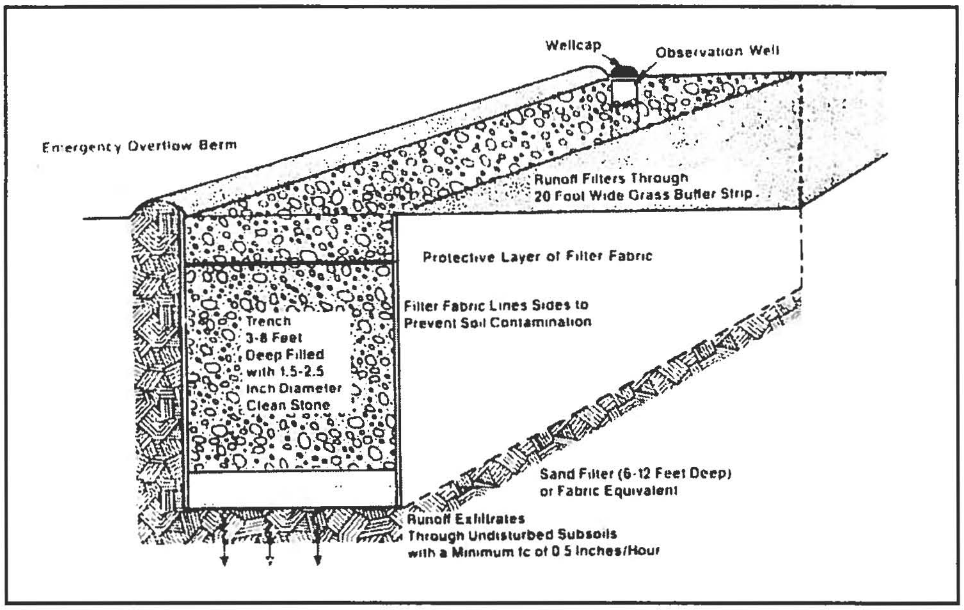


Figure 3-5. Schematic design of a coventional infiltration trench *Source: Schueler, 1987*

Effectiveness/Advantages

- Infiltration trenches can provide groundwater recharge, baseflow augmentation, and partial control of streambank erosion immediately downstream of the site (Shueler 1987).
- Based on estimates from studies of rapid infiltration land wastewater treatment systems and pollutant transport modeling, properly functioning infiltration trenches are considered to be highly effective at removing particulate pollutants (sediment, trace metals, coliforms and organic material) and moderately effective at capturing dissolved constituents.
- This technology is best-suited to highly constrained urban settings with appropriate soils and a reliable maintenance plan.

Constraints

- According to Schueler et al. (1992), one in five infiltration trenches fail to operate as designed immediately after construction; over half partially or totally fail within five years of construction, primarily from clogging.
- Infiltration trenches are relatively expensive to construct and have limited storage capacity.

Operations and Maintenance

Routine inspection and maintenance of infiltration trenches is critical for sustained function. Maintenance includes annual inspections of the trench and buffer strip, wet weather infiltration performance monitoring, mowing of the buffer strip and periodic sediment removal.

I. Porous Pavement

Description

Porous pavement describes a variety of techniques used to create roadways, parking lots, and other transportation surfaces which promote water infiltration; they are a substitute for conventional concrete and asphalt impervious surfaces. In a properly functioning system, water stored in the sub-pavement layer infiltrates into an adjacent uncompacted soil layer, recharging and filtering the water rather than releasing it as surface runoff. When properly designed and installed, this pavement has load bearing strength, longevity and maintenance requirements similar to conventional pavement. This BMP removes stormwater pollutants (principally via soil infiltration) and helps maintain the pre-development hydrologic regimen (reduction of runoff peak flows and enhancement of creek baseflow). Figure 3-6 presents a schematic design for a typical porous pavement configuration. Design options include:

- *Porous pavement with underground storage/recharge beds.* This design offers maximum infiltration capacity and storage and can be used for heavily trafficked areas in small to very large applications. The rock-filled bed underlying the porous pavement surface is composed of approximately 40% void space suitable for runoff storage. Water is held in this area until it percolates down into an uncompacted soil subgrade below.
- *Concrete pavers infilled with soil/gravel and vegetated with grass.* Numerous products have been devised for light-duty traffic (car parking only, foot traffic, etc.) which use interlocking or modular concrete pavers. Unless the use is light, the sub-grade of these systems can become compacted limiting infiltrative capacity and performance as a water quality management tool.

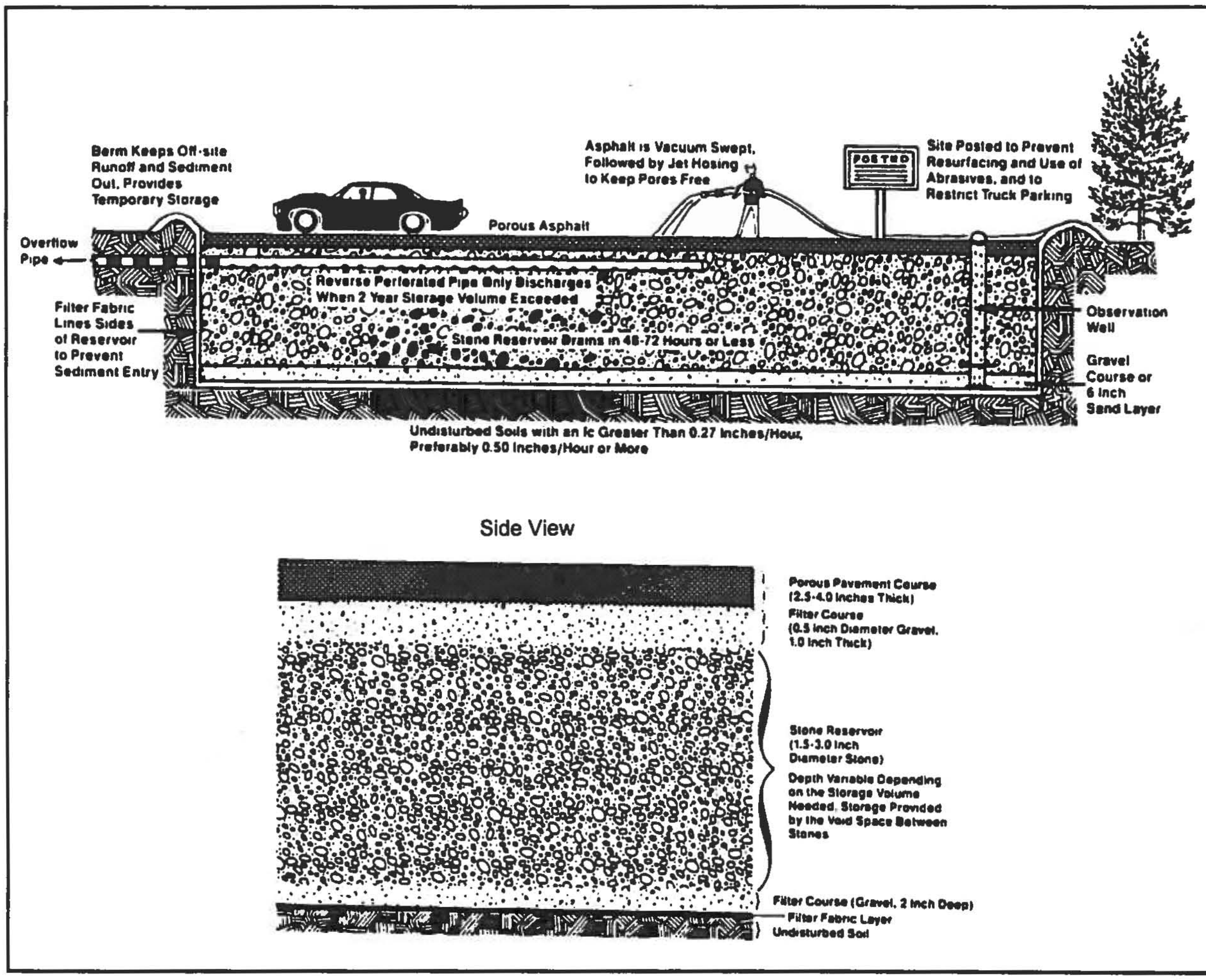


Figure 3-6. Schematic design of a porous pavement system *Source: Schueler, 1987*

- *Plastic or metal grid infilled with gravel or equivalent.* Numerous products have been devised to provide a structure for the use of porous materials such as gravel. These are also generally useful only with light-duty traffic.

Applicability

Porous pavement use is recommended where well-drained soils can support long-term infiltration. However, porous pavement is generally used in low-traffic flow areas (parking lots, lightly used roads and driveways, etc.) since pavement designs in these areas require less excavation and expense, and since long-term clogging threats are reduced. Porous pavement projects are generally recommended for sites with gentle slopes, although they have been executed successfully on sloping sites with beds that were properly terraced. This technology has a mixed record of success and failure, largely dependent upon the diligence with which it is designed, installed, and maintained. The perception that this technology is prone to clogging has limited its widespread use in Austin.

Effectiveness/Advantages

- By mitigating the effects of impervious cover, porous pavement addresses the major negative component of urbanization on water quality and quantity by mimicking the pre-development hydrologic regimen (less runoff, more infiltration than for impervious surfaces).
- Widespread application of this technology can provide significant water quality, flood and erosion problems management. Modeling studies show that while the pollutant contribution of an individual parking area may be small, combined loadings from these areas represent a major source of NPS pollution (City of Austin, 1992).
- If properly designed, constructed and maintained, porous pavement is effective at removing both suspended and soluble pollutants. Cahill Associates (1993) reports the following removal rates: TSS (>95%), TN (88%), TP (>60%), COD(83%), Pb (>95%), and Zn (>99%).

Constraints

- Overall, porous pavement systems have a 75% failure rate (due to partial or total clogging) within 5 years. Failure is attributed to inadequate construction techniques, low permeability soils or restricting layers, heavy vehicular traffic and resurfacing with non-porous pavement materials (Schueler et al., 1992). Some studies have indicated porous pavement to be a successful stormwater management tool if properly designed and installed (Cahill Associates, 1993).
- Porous pavement systems require somewhat demanding site conditions, similar to those for infiltration basins: well-drained underlying soils, substantial depth to bedrock, 2-4 foot minimum depth to the seasonally high water table, shallow slopes, etc. Most of these factors can be designed for, although at greater cost. In Austin, few areas have favorable soils and underlying geology.
- To minimize clogging potential, porous pavements should be used only in parking lots or for light traffic use areas.
- Regular maintenance is essential including jet hosing and vacuum sweeping to prevent

clogging. Maintenance to remediate clogging at the sub-pavement soil interface is generally not practical.
- Innovative design, extensive site preparation and analysis, and specialized construction requirements make this approach more expensive than conventional paving technologies.

Operations and Maintenance

The porous pavement surface should be vacuum swept from one to four times per year, depending on the pavement use and activity intensity, although instances are documented in which a porous pavement system has operated successfully for years with no maintenance at all. High-pressure jet hosing, to keep the asphalt pores open, has been both recommended (Schueler, 1987) and advised against (Cahill Associates, 1993). Field data indicate that in many cases, this routine maintenance practice was not followed (MWCG, undated). Other maintenance requirements include inspection, patching and relieving surface clogging.

J. Rainwater Harvesting

Description

Rainwater harvesting diverts stormwater runoff from building roofs into a holding tank or cistern via gutters and pipes. Figure 3-7 shows an example rainwater harvesting setup. As with irrigation-based pond BMPs, stored water is irrigated onto landscapes or other pervious surfaces such that little or no runoff occurs. This technology reduces peak runoff flows, enhances vegetative growth, and promotes infiltration. Rainwater systems usually take runoff exclusively from rooftops. This water is relatively clean compared with road or fertilized turf runoff. While this reduces pollutant removal performance with respect to other BMPs which treat more polluted runoff, the high quality captured water makes its use more flexible. Rooftop runoff typically composes a significant portion of total site imperviousness (approximately 50% for residential and 25% for commercial properties).

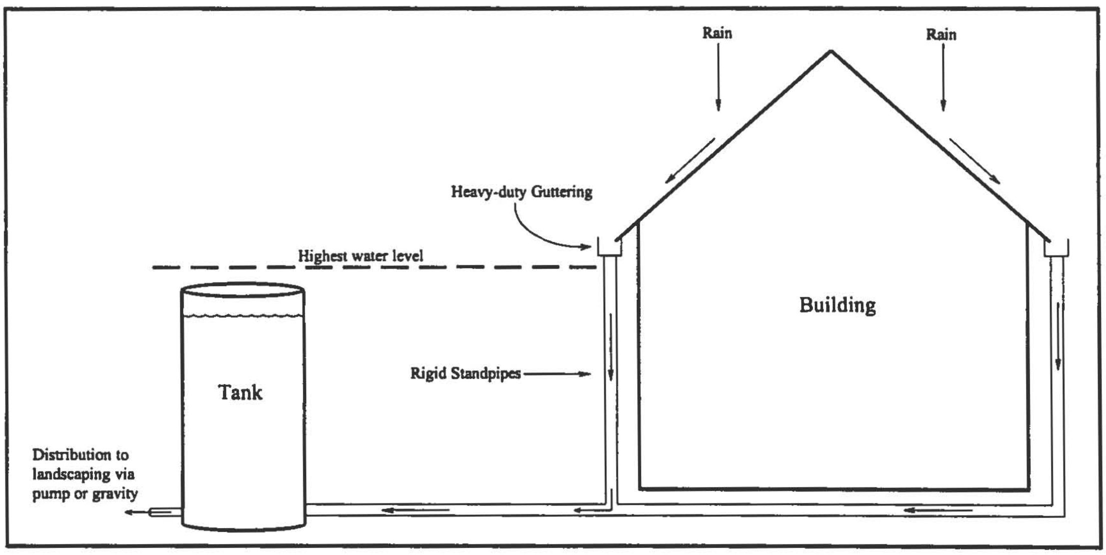


Figure 3-7. Schematic of a rainwater harvesting system *Source: Loomis & Moore*

Applicability

Rainwater harvesting systems are widely applicable for residential or commercial properties where there is sufficient pervious area or drinking water need to use the stored water. Rainwater harvesting systems can be relatively simple to install on existing structures, requiring only a small area for the tank and pump house. A wide range of available designs can accommodate varying required storage volumes. In general, rainwater collection requires only a relatively simple installation procedure using commonly available materials.

Effectiveness/Advantages

- Implemented on a widespread basis, rainwater harvesting can provide substantial reductions in runoff volume, peak flow rates, and receiving channel erosion.
- Rainwater systems can generally be more easily retorit into heavily urbanized areas than pond stormwater management practices.
- Rainwater systems have the important ancillary benefit of conserving water, a City of Austin priority.
- As a water quality control, rainwater harvesting can be used in tandem with conventional detention/retention BMPs. While rain harvesting may capture relatively cleaner runoff, runoff volumes to water quality ponds is reduced yielding: (1) the ability to use smaller pond facilities; or (2) enhanced pollutant removal performance in existing ponds.
- Promoted in conjunction with water conservation goals, the water quality benefits of rain harvesting are more attractive.

Constraints

- Rooftop pollutant concentrations are generally low, thus uplands constituent load reductions are minimal.
- Many rooftops do not now have direct hydrologic connections with the storm sewer system, thus a significant portion of roof runoff already drains to pervious areas. However, given the frequent occurrence of over-fertilization, a more uniformly metered application of roof runoff across these areas is still beneficial.
- Rain harvesting system operators may choose to keep cisterns full until dry weather requires pervious area irrigation, thereby limiting available runoff capture volume.
- A detailed cost-benefit analysis of rainwater systems in the Barton Springs Zone found that the cost per pound of TSS removed is about an order of magnitude (ten times) higher for rain harvesting systems than for conventional structural water quality alternatives such as retention-irrigation (Loomis & Associates, 1995).
- Widespread application of rain harvesting may be impractical due to the need for a dedicated and knowledgeable system operator/user to promote maximum performance and assure adequate maintenance.

Operations and Maintenance

Rainwater system designs vary greatly in complexity and requirements for upkeep. However, they are generally not passive systems and thus require a relatively high degree of attention from the system operator/user. Maintenance activities include system inspection and repair. For optimal water quality benefits, the user must monitor cistern water levels. Maintenance costs can be partially offset by savings in water usage.

K. CHECK DAMS

See page 3-75.

L. HAZARDOUS MATERIALS TRAPS

Description

Hazardous materials traps (HMTs) are retention basins, usually made of concrete, designed to capture hazardous material spills along roadways. HMTs are sized to capture the contents of a standard tanker truck or rail car (approximately 8,000 gallons). They can be retrofit below bridges (which often pass runoff directly into waterways via open drainage slots) or at storm drain outfalls adjacent to sensitive creeks. Figure 3-8 presents a schematic of a hazardous materials trap. To function as intended, HMTs should be empty at the time of a spill, and thus most are fitted with an inverted siphon to drain captured stormwater.

Applicability

Hazardous materials traps are generally useful in locations such as bridge and roadway crossings where a hazardous materials spill would have rapid access to sensitive receiving waters. Since the potential number of toxic spills occurring during transport accidents is small, the expected volume of pollutants prevented from contaminating waterways on a long-term basis is also low. A single high volume spill episode is capable of devastating Barton Creek or Lake Austin. Many of the transportation accidents that spill materials on bridges do not release the entire volume at once. Spills can often be contained by proper response teams. However, bridge hazardous materials containment structures can prevent contamination from toxic substances even if response time is long.

Effectiveness/Advantages

- HMTs are an effective and reliable mechanism for reducing the potentially catastrophic pollution event risk for sensitive waterways.

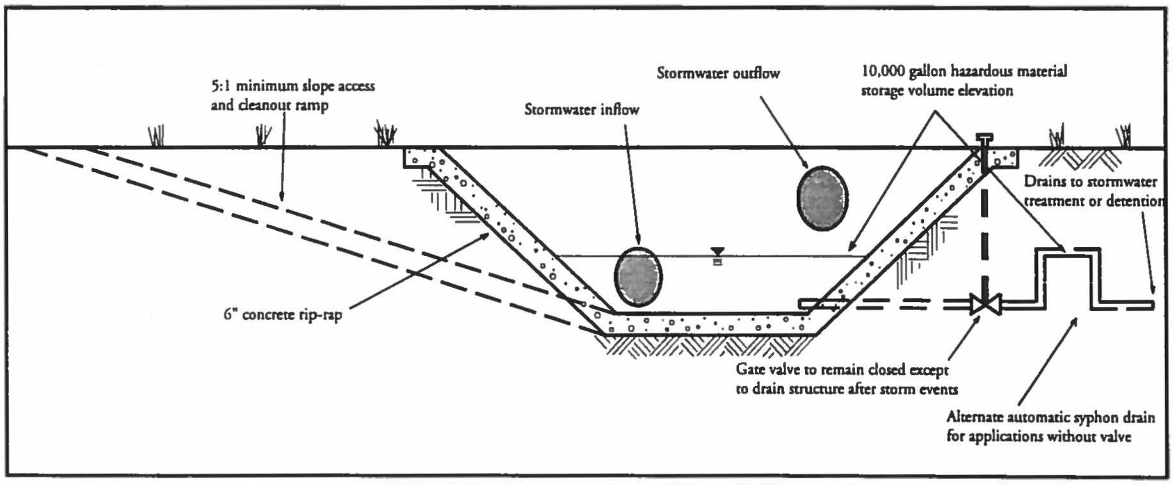


Figure 3-8. Schematic design of a hazardous materials trap *Source: Loomis & Moore*

Constraints

- Containment during rainfall events may be poor due to the potentially large volumes of runoff mixed with spilled contaminants or in the event a vehicle leaves a bridge and falls directly into the receiving water.
- Significant and expensive structural and drainage retrofits would be necessary to concentrate runoff on bridges crossing large waterways such as Town Lake.
- Maintenance costs are potentially high. HMT structures have to be drained after every rainfall event. Typically, a siphon device is used to drain ponds when they are full; however, these devices can and do fail or clog thus regular inspection and maintenance is necessary to insure that the required storage volume is available.

Operations and Maintenance

The City's spill response team would have the charge of cleaning up after spill events. As noted above, consistent inspection and sometimes maintenance of the HMTs is necessary to assure that facilities are drained or are draining after all rainfall events to ensure that their full capture volume is available.

3.1.2 Stormwater Treatment Measures

A. Retention-Irrigation

Description

Retention/irrigation refers to the capture of stormwater runoff in a holding pond and subsequent use of the captured volume for irrigation of landscape areas. This technology is very effective in that, for the captured water quality volume, it provides virtually no discharge to receiving waters and high stormwater pollutant removal efficiencies. This technology mimics natural undeveloped watershed conditions wherein the vast majority of the rainfall volume during smaller rainfall events is infiltrated through the soil profile. Retention-irrigation facilities function to remove pollutants primarily via capture and vegetative uptake in the upper soil profile and shallow root zone. Figure 3-9 presents a schematic design for a typical retention-irrigation system.

Capture of stormwater can be accomplished in almost any kind of runoff storage facility, ranging from fully dry, concrete-lined ponds to those with vegetated basins and permanent pools. The pump and wet well should be automated with a rainfall sensor to provide irrigation only during periods when required infiltration rates can be realized. Generally, a spray irrigation system is required to provide an adequate flow rate for distributing the water quality volume (LCRA, 1996).

Applicability

Retention/irrigation systems are used in areas with sufficient space for a holding pond and with landscaped areas of sufficient size to distribute the pond volume as irrigation.

Although performance is excellent, maintenance requirements and construction costs for retention-irrigation systems are high; this approach is therefore most often applied in more

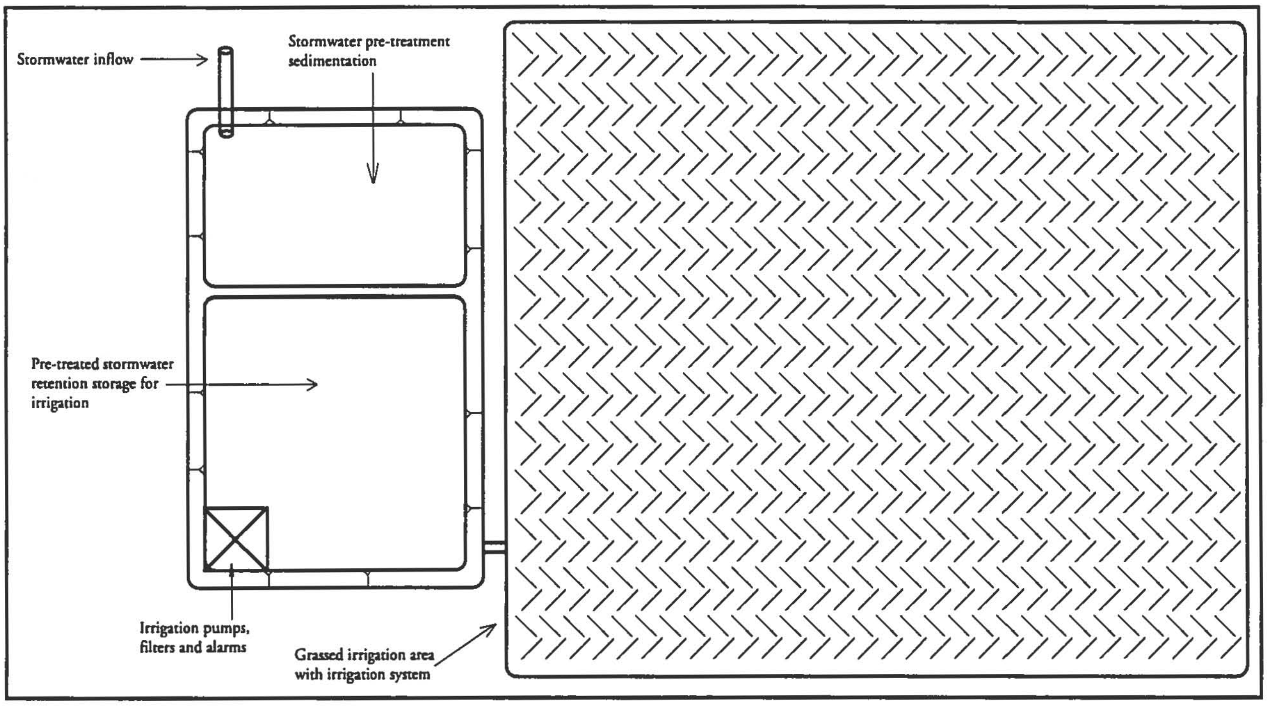


Figure 3-9. Schematic design of a retention irrigation system *Source: Loomis & Moore*

sensitive watersheds. Retention/irrigation systems have been commonly used for development in the Barton Springs Zone as they offer a means of achieving non-degradation: preservation of pre-developed flow rates and pollutant loads.

Effectiveness/Advantages

- Pollutant removal effectiveness is high, accomplished primarily by: (1) sedimentation in the primary storage facility; (2) physical filtration of particulates through the soil profile; (3) dissolved constituents uptake in the vegetative root zone by the soil-resident microbial community.
- The hydrologic characteristics of this technique are effective for simulating pre-developed watershed conditions through: (1) containment of higher frequency flood volumes (less than about a 2-year event); and (2) reduction of flow rates and velocities for erosive flow events.
- The City of Austin estimates 90% removal of sediment, nutrients, and toxics. With an additional 90% multiplier to account for down-time, the City assumes an 81% overall pollutant removal effectiveness for the captured water quality volume (City of Austin, 1997b).

Constraints

- Retention-irrigation is a relatively expensive technology due primarily to mechanical systems, power requirements, and high maintenance needs.
- Due to the relative complexity of irrigation systems, they must be inspected and maintained at regular intervals to ensure reliable system function.
- Retention-irrigation systems use pumps requiring electrical energy inputs (which cost money and can be interrupted). Mechanical systems are also more complex, requiring

skilled maintenance, and they are more vulnerable to vandalism than simpler, passive systems.

- Retention-irrigation systems require significant open space and thus may be difficult to retrofit in urban areas.

Operations and Maintenance

The irrigation system should be inspected about 6 times annually to ensure proper operation. Two or more inspections should occur during or immediately following wet weather. Sediment will require removal from the inlet structure/sediment forebay and around the sump area at least twice annually or when the depth reaches 3 inches (LCRA, 1996). In the past, City of Austin Public Works staff have expressed strong reservations about irrigation facilities, in particular because they may require excessive maintenance (Loomis & Moore, 1995).

B. Wet Ponds

Description

Wet ponds are water quality management facilities with a permanent wet pool designed to detain and treat stormwater runoff. Figure 3-10 presents a schematic of a wet pond. This technology provides potentially excellent stormwater quality enhancement for a wide range of stormwater constituents. Permanent wet storage may serve as a stand-alone BMP or may be used in conjunction with other measures such as erosion control, flood control, or baseflow storage. Wet ponds are designed to encourage the maintenance of healthy emergent and submerged aquatic vegetation and an active microbial community capable of dissolved constituent consumption. If properly designed and sized, sedimentation processes are also effective in capturing the particulate fraction and pond inflows replace part or all of the prior water

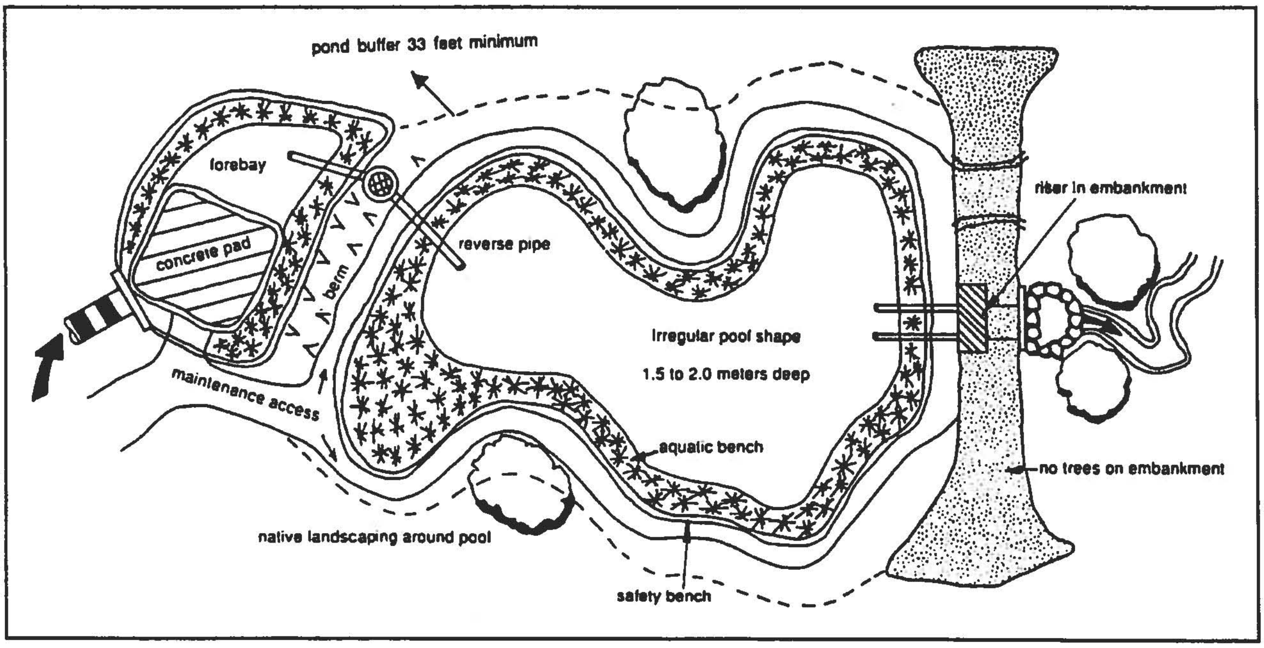


Figure 3-10. Schematic design of an enhanced wet pond system *Source: Schueler, 1991*

quality volume. The new inflows are stored and "treated" until the next runoff event. Pollutants are also removed in wet ponds through algal settling and bacterial decomposition (Schueler et al., 1992).

Wet pond permanent pools are generally designed deep enough to prevent resuspension of sediment particles and are sized corresponding to some or all of a design storm runoff volume. Reliable rates of pollutant removal can be obtained with pool sizes corresponding to a range of 0.5 to 1.0 inches of runoff per acre of impervious surface (Schueler et al., 1992). Enhanced wet ponds can be designed with a forebay where trapped sediment can be easily removed and aquatic benches that can support a fringe wetland around the perimeter of the pond, increasing sediment and soluble pollutant removal. Additional benefits include creation of aquatic, wetland and terrestrial habitat and high community acceptance if designed as an attractive urban amenity.

Applicability

Wet ponds may be constructed on- or off-line and can be sited at feasible locations along established drainage patterns, concentrating on small subwatersheds with residential land uses or other uses where high nutrient loads are expected (such as golf courses). They are typically used only in drainage basins of more than ten acres and less than one square mile. Emphasis can be placed in siting wet ponds in areas where the pond can also function as an aesthetic amenity or in conjunction with other stormwater management functions. Wet ponds have been used over a broad range of storm frequencies and sizes, drainage areas and land use types.

Effectiveness/Advantages

- Due to the presence of the permanent wet pool, properly designed and maintained wet ponds can provide significant water quality improvement across a broad spectrum of constituents.
- Wet pond effectiveness is highly dependent upon adequate sizing of the permanent pool. City of Austin investigations have made recent estimates of performance using monitoring data for Austin wet ponds. Two primary design parameters were correlated to performance: (1) the permanent pool volume (VB); and (2) the runoff volume generated by the mean annual storm (VR). The City has found that pollutant removal efficiencies correlate well to the VB/VR ratio (City of Austin, 1997b).
- City data show wet ponds to be effective in removing sediment (43-82%), effective (among structural BMPs) in removing nutrients (38-66% for DP), and variable for toxics (11-70% for COD). These removal figures include a 90% maintenance factor, meaning that they are assumed to operate at 90% of their potential capacity in the long term (COA, 1997b).
- If properly designed, constructed and maintained, wet ponds can provide substantial aesthetic/recreational value and wetlands habitat.

Constraints ?

- ? A reliable dry-weather baseflow is generally required to maintain pool elevations and prevent algal matting and stagnation. why
- The use of these ponds may be limited in very urban areas due to space constraints and suppressed baseflow.
- Wet ponds are subject to the same safety concerns of all open water bodies; however,

designs incorporating shallow littoral benches can minimize safety concerns.

- Wet ponds must be periodically dredged of trapped sediments and pollutants to maintain the design storage volumes. Dredging procedures are generally expensive and time-consuming.
- Wet ponds can require significant physical space and may be difficult to retrofit in urbanized areas.

Operations and Maintenance

The primary and most costly maintenance requirement for wet ponds is periodic removal of accumulated sediment (generally at 10-20 year intervals) to assure availability of the design water quality volume. Additional maintenance requirements include routine inspections, mowing of buffers and embankments, removal of trash and debris from the forebay and outflow structures, inspection and repair of structural elements, and control of nuisance problems such as insects, weeds, odors and algae. Preliminary field assessments have found most conventional wet ponds functioning as designed and few have failed (ref. in Schueler et al., 92).

C. Constructed Stormwater Wetlands

Description

Constructed stormwater wetlands are shallow, vegetated ponds engineered to mimic the structure and function of naturally occurring wetlands. Figure 3-11 presents a schematic representation of a constructed stormwater wetlands facility. Although design configuration options are relatively flexible, constructed wetlands generally feature permanent pool depths of approximately 1.5-feet and combine long residence times with natural plant and biological communities to remove a wide range of pollutants from stormwater. Natural wetlands have a

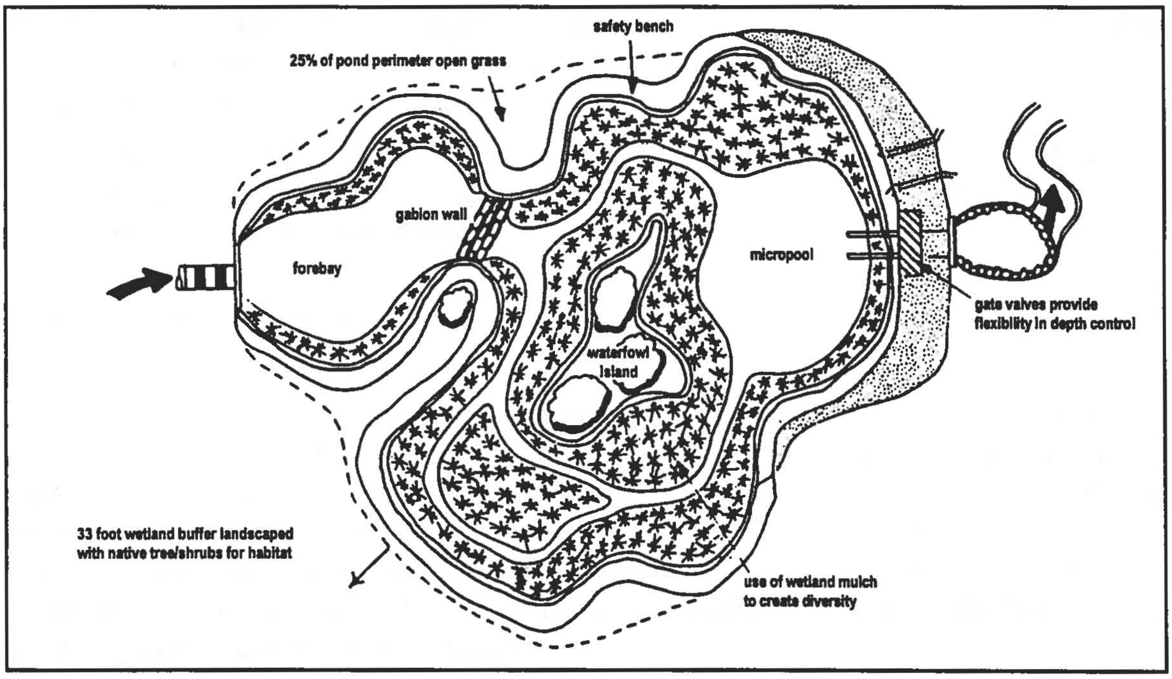


Figure 3-11. Schematic design of an enhanced shallow marsh system *Source: Schueler, 1991*

well-recognized ability to trap sediment, provide a sink for toxics, and utilize nutrients in stormwater. They can be designed as aesthetically appealing amenities and can serve as wildlife habitat in relatively urban settings.

Applicability

Constructed stormwater wetlands are applicable in many development situations where sufficient baseflow, groundwater and/or contributory drainage area is available to maintain normal pool elevations. Constructed wetlands can be designed as either on- or off-line facilities and can be used in contributing drainage areas as small as 5 acres.

Effectiveness/Advantages

climate problems

- Wetlands, like wet ponds, provide moderate to high levels of pollutant removal for a wide range of constituents, with highest observed efficiencies occurring during the growing season.
- If properly designed, constructed and maintained, wetlands provide significant aesthetic and habitat value.

Constraints

- Baseflow to the wetland must be adequate to maintain aquatic vegetation cover through dry periods. Maintenance of appropriate water levels in the wetland can be a problem in areas where soils are sandy or alluvial, or otherwise tend toward rapid infiltration (although liners can be used to overcome this problem).
- Because of high surface to volume ratios due to shallow depths, stormwater wetlands require more space than most other types of pond BMPs. Siting these features therefore may be difficult in urbanized areas.
- Wetland/marsh areas may be viewed as aesthetic and pest nuisances by the public if not properly inspected and maintained.
- Wetlands performance monitoring has indicated cases of negative removal of ammonia and soluble phosphorus (Schueler et al., 1992).

Operations and Maintenance

Artificial wetlands require a larger commitment to maintenance during the first 1-3 years to ensure proper establishment of wetland/marsh vegetation. Thereafter, maintenance requirements are similar to other pond systems.

D. SEDIMENTATION/SAND FILTRATION

Description

Sedimentation/filtration ponds are structural control devices providing two-stage treatment of stormwater. The sedimentation basin detains first flush runoff, generally at least the first ½-inch, with minimum drawdown times in the sedimentation basin of approximately 24 hours. In the sedimentation basin, removal of a substantial fraction of the floatable and suspended solids is intended to prevent premature clogging of the filter media surface and enhance overall pollutant removal by the filter. Figure 3-12 presents a schematic of a sedimentation-filtration system as typically implemented in Austin.

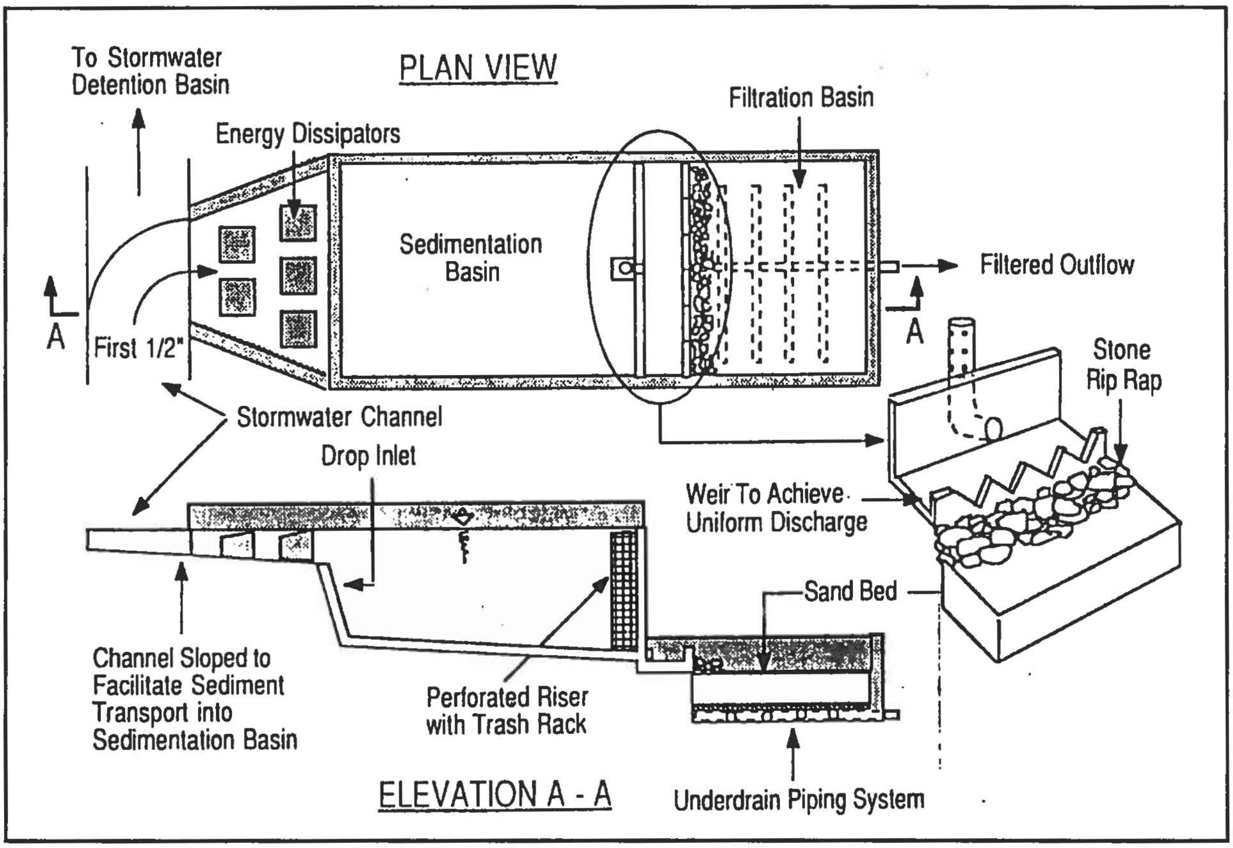


Figure 3-12. Conceptual sedimentation-filtration system *Source: City of Austin. 1988*

Sedimentation pond effluent is discharged slowly to the filtration basin. The standard City of Austin filtration design includes a 12-inch sand filter, a geotextile layer, and 6 inches of gravel. A perforated PVC piping system drains filtered flows from the gravel volume. Sand filters remove pollutants primarily through physical filtration. However, some chemical removal processes occur and some biodegradation may be provided by microbial populations affixed to the sand media. Alternative filtration media types can include limestone, peat, geotextile fabrics, zeolites, or sorbent filter media (Schueler et al., 1992).

Applicability

Sedimentation/filtration ponds are typically used to treat runoff from small, newly-developed sub-watersheds. In Austin, this approach has been widely implemented because design configurations are flexible and construction materials generally inexpensive (unless constructed with reinforced concrete). Sedimentation/filtration facilities are not recommended for use with runoff from areas with high concentrations of dissolved constituents (for example, nitrate or dissolved phosphorous). Sedimentation/filtration ponds are occasionally used as pre-treatment for other types of pollutant removal measures, such as infiltration techniques and vegetative filter strips.

Effectiveness/Advantages

- Sedimentation/sand filtration can achieve high levels of removal for suspended solids (85%) and associated toxic loads (65%) (City of Austin, 1997b). The main factors that influence overall removal rates for the filtration basin are loading rate (filtration surface area) and filter media type.
- Designs for sedimentation/filtration facilities are flexible and well-suited for retrofit in tightly-constrained urban locations. Materials costs are relatively low (unless significant reinforced concrete is used).
- Ancillary benefits associated with capture and slow release of the water quality volume include erosion and flood control and baseflow enhancement.

Constraints

- Sedimentation/filtration facilities generally provide negligible or negative removal efficiencies for dissolved constituents including nutrients (City of Austin, 1997b).
- If not maintained, clogging of the filter surface and bypass of the "first-flush" pollutants can occur; however, proper sedimentation basin design can significantly reduce this problem.
- This technology requires substantial grade differentials to promote gravity flow through the flow splitter, the sedimentation basin outlet, the filter media, the underdrain, and the outlet structure.
- Sedimentation-filtration facilities are often perceived to be less attractive than permanent pool BMPs.

Operations and Maintenance

Sedimentation/sand filtration facilities require, at a minimum, inspection of the basins after every major storm for the first six months after construction, and annually thereafter to assess: (1) sand filter clogging; (2) sediment accumulation on the sand media and in the sedimentation basin; (3) trash and debris accumulation; (4) vegetative growth in the sand media; and (5) the structural integrity of drainage appurtenances such as inflow and outflow structures.

E. Extended Detention

Description

Extended detention (ED) refers to the capture and slow release of stormwater runoff. Figure 3-13 presents a schematic of an enhanced extended detention design. Extended detention can be used to target multiple stormwater management missions including water quality control (through deposition and capture of suspended solids and associated toxics); erosion control (through capture of the 6-month to 2-year runoff volume); baseflow enhancement (through extremely slow release of a portion of the captured runoff volume); and flood control for higher frequency events (through provision of watershed storage). ED ponds can be designed in conjunction with other structural water quality management practices (such as wet ponds) or as stand-alone facilities.

Applicability

Extended detention technologies are applicable in areas where sufficient open land and grade is available to place a stormwater storage facility. Used as a dry facility, extended detention can

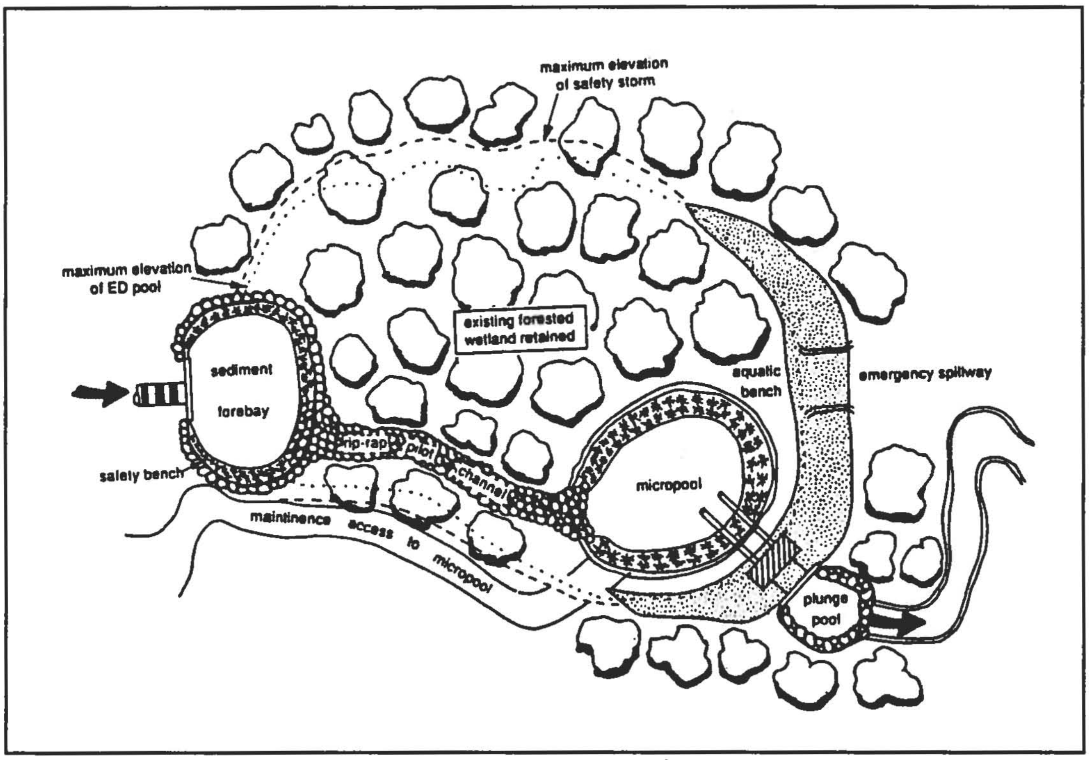


Figure 3-13. Schematic design of an enhanced dry extended detention pond system *Source: Schueler, 1991*

provide significant erosion protection through capture and metered release of storm flows without harming riparian vegetation or habitat. Used in conjunction with wet storage, extended detention can provide erosion control and slow release of clean flows for baseflow augmentation.

Effectiveness/Advantages

- Depending on detention time, ED ponds can provide moderate to high, although variable, particulate pollutant removal. Since settling is the primary pollutant removal mechanism, removal rates could be excellent if the target pollutant is particulate in form, whereas removal can be very limited for soluble pollutants. As a water quality facility, the City of Austin estimates performance at 40% removal for sediment (50% x 80% "maintenance factor") and 24% for toxics (COD) (City of Austin, 1997b).
- As a flood control practice, ED ponds are effective in reducing peak discharge rates for the design storms for which they are built. Rainfall modeling analyses for the Washington, D.C. area indicate that hydrologic control of both the 2- and 10-year design storms volumes would be sufficient to adequately control the entire spectrum of many expected flood frequencies from most drainages (Schueler, 1987).
- As a baseflow enhancement measure, extended detention (used in conjunction with wet storage) can provide direct and reliable increases in baseflow rates and volumes.
- As an erosion control practice, adequately-sized ED facilities can limit downstream flow rates to below erosion threshold levels.

Constraints

- As a water quality BMP, extended detention provides negligible control of dissolved constituents, including nutrients.
- ED ponds are generally not used in already developed, highly urbanized areas because of space constraints, but can be used to retrofit existing flood control facilities.
- Unless bypass structures are adequately designed, high flows may result in re-suspension of deposited materials.
- As a baseflow augmentation strategy using slowly-released urban runoff, water quality enhancement measures must be in place to prevent long-term toxicity to downstream populations.
- Significant reductions in suspended sediment concentrations and capture of bedload may result in increased flow energy and downstream erosion.
- Extended detention facilities are generally perceived to be less attractive than permanent pool practices.

Operations and Maintenance

The primary and most costly maintenance requirement for extended detention facilities is periodic removal of accumulated sediment (generally at 5-20 year intervals). Additional maintenance requirements include routine inspections, mowing of buffers and embankments, removal of trash and debris from the forebay and outflow structures, inspection and repair of structural elements, and control of nuisance problems such as insects, weeds, odors and algae. For all extended detention facility uses, maintenance of design stage-discharge relationships is critical to proper performance.

F. Grassed Swales

Description

Grassed swales are vegetated, graded-channel drainage systems as shown in Figure 3-14. Swales can often be used as an alternative to curb and gutter/storm sewers systems in urban areas. In the conventional application, they are covered with a dense erosion-resistant grass, and can provide conveyance of stormwater runoff while promoting infiltration, settling and capture of particulates, biological uptake processes, and physical filtration. Swale performance is directly proportionate to application time, thus longer swales with slower flow velocities afford a greater opportunity for water quality enhancement processes. Hydrologic performance can be improved if check dams are installed to temporarily pond runoff (Schueler, 1987).

Applicability

Grasses swales are appropriate as an alternative to curb and gutter drainage systems in single-family residential subdivisions and on highway medians. They can also be used as an aesthetic, passive BMP for targeting water quality improvement for site development drainage. A minimum swale length of 150 feet is mentioned in the literature as necessary for adequate performance. Swale performance is proportional to swale length, flow depth, and flow velocity. They are generally poorly-suited to retrofit application due to space constraints. Swales are not recommended for construction on slopes greater than 5%. Longitudinal slopes should be as flat as possible (without promoting ponding and stagnation) and not greater than about 5% to prevent excessive flow velocities and minimal contact time (Schueler et al., 1992).

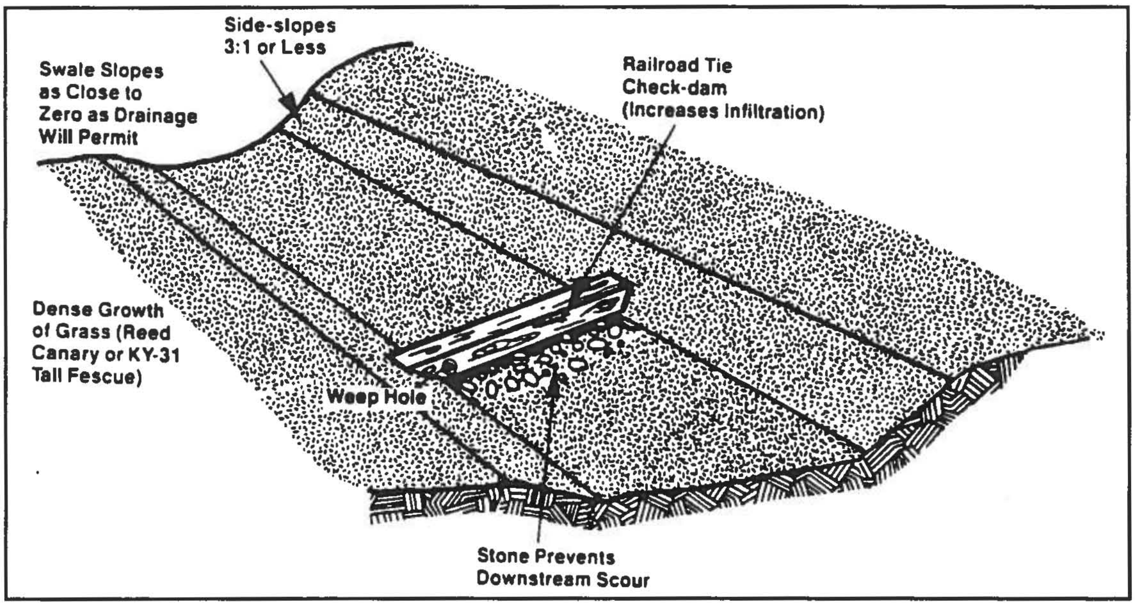


Figure 3-14. Schematic design of an enhanced grassed swale *Source: Schueler, 1987*

Effectiveness/Advantages

- If properly designed, constructed and maintained, grass swales are effective as water quality measures, reliable and passive as a drainage system, and potentially aesthetic in comparison to curb-and-gutter storm sewer drainage approaches.
- Particulate pollutant removal has shown mixed results in field monitoring. Removal efficiencies have been reported from low to high in different areas with different soil, flow velocity/depth, and grass cover characteristics (Schueler et al., 1992). Removal efficiencies for swales are conservatively estimated to be 40% for TSS, 0% for DP, and 24% for COD (toxics).

Constraints

- Sources report variable grassed swale performance capabilities and the high potential for negligible effectiveness if shallow, slow velocity flow is compromised in the swale.
- Proper design is critical. Water quality performance tends toward zero when flow depths exceed 2-3 inches or runoff velocities are greater than about 3 feet per second.
- Except to the extent that infiltration is promoted, swales generally provide negligible soluble nutrients removal (Schueler, 1987).
- Swales are generally poorly-suited for retrofit application in established neighborhoods or highly urbanized areas due to space constraints.

Operations and Maintenance

Routine swale maintenance primarily involves regular mowing, occasional spot re-seeding and weed control. Special care including watering and erosion prevention activities are critical in the first few months of swale establishment.

G. Vegetated Filter Strips

Description

Vegetated filter strips are vegetated areas designed to accept runoff as overland sheet flow from developed land uses. Figure 3-15 presents a filter strip schematic. Vegetation forms can vary from grassy meadow to woodlands but must be graded and maintained to enhance sheet flow and discourage concentrated flow. Filter strips provide water quality enhancement through infiltration, settling and capture of particulates, biological uptake processes, and physical filtration. Vegetative filter strips mimic natural watershed conditions by promoting localized runoff storage and infiltration. Filter strips can be vegetated to preserve the character of riparian corridors and prevent streambank erosion as well as to provide urban wildlife habitat.

Properly functioning filter strips are characterized by: (1) shallow, sheet flow, typically distributed across the filter strip by a flow spreading device; (2) dense vegetation with erosion resistant species that effectively bind the soil; (3) flat grades with uniform, shallow slopes; and (4) a length at least as long as the contributing runoff area (Schueler, 1987). The top of the filter strip should directly abut the contributing area to avoid flow concentration. Filter strips should be at least 20 feet long, with better performance obtained from strips 50-75 feet in length (Schueler, 1987).

Applicability

Filter strips are applicable in locations where sheet flow can be achieved and a sufficient area of robust vegetation installed or maintained. Some potential locations include park areas adjacent to roadways, landscaping areas adjacent to or within parking lots, and landscaping areas surrounding buildings that could receive roof runoff. Use of this alternative is appropriate where structural controls may interfere with surrounding uses, such as in parks and golf

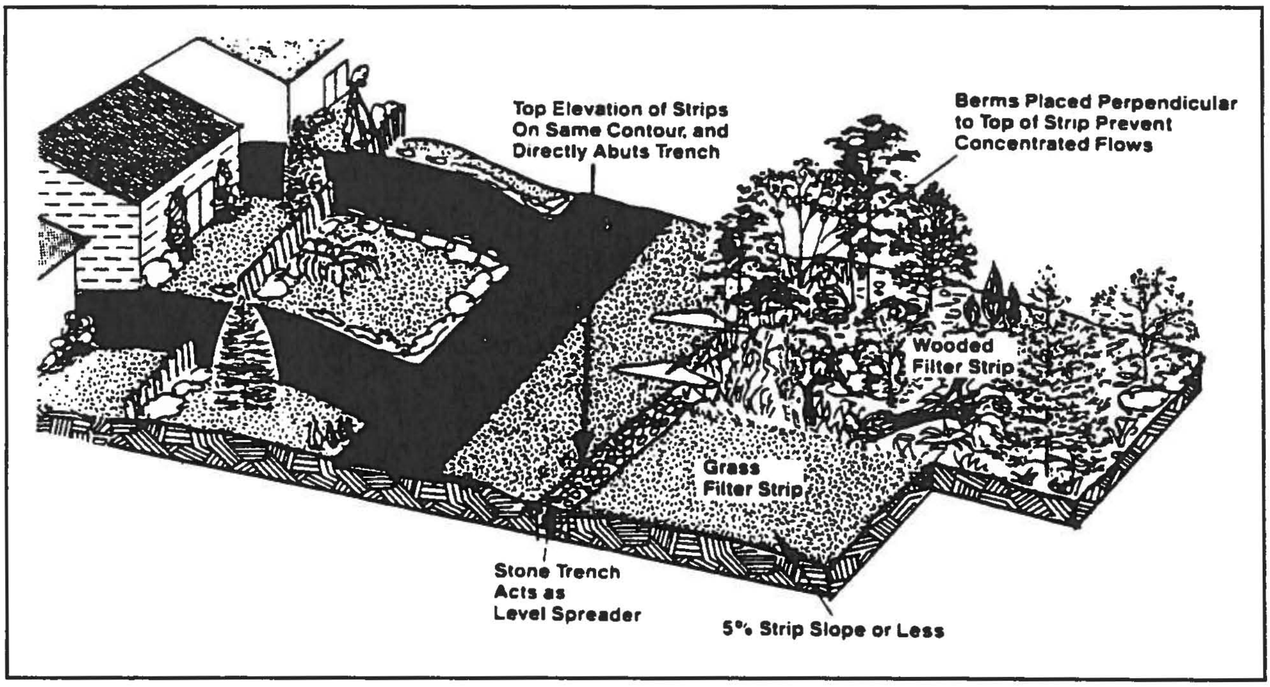


Figure 3-15. Schematic design of a filter strip *Source: Schueler, 1987*

courses. Filter strips are also frequently used as a pretreatment measure to infiltration systems or to provide secondary treatment when used in series with other BMPs. The recommended maximum contributing drainage area for a filter strip is five acres. Filter strips are most feasible in climates that can sustain plant growth on a year-round basis (Schueler et al., 1992).

Effectiveness/Advantages

- In general, the rate of pollutant removal for filter strips is a function of length, slope, soil permeability, size of the runoff area, runoff velocity, runoff depth and vegetation type.
- If flow depth and velocity are not excessive, vegetated filter strips are effective in removing particulate pollutants. The maximum expected percentage of sand, silt and clay fractions is trapped by grass buffers at widths of 10, 50 and 400 feet, respectively. For a 3% slope, the estimated efficiency for total sediment removal ranges from 75% for a 50-foot wide filter to 95% for a 300-foot wide filter (City of Austin, 1992).
- Capture of dissolved constituents is best correlated with infiltration percentage. Infiltration is enhanced in applications with large filter areas, slow velocities, shallow depths, dense vegetation, and well-drained soils.
- Forested filter strips appear to have greater nutrient removal than grassed strips (Schueler, 1987).
- If adequately vegetated, graded and maintained, vegetated filter strips are effective as water quality measures, reliable and passive as a drainage system, and potentially aesthetic in comparison to structural water quality control measures.

Constraints

- In practice, runoff over unmaintained filter strips and filter strips accommodating excessive flow tend to concentrate and form eroded gullies. Concentrated flows result in negligible constituent removal effectiveness.
- Filter strips work best during the active growing season.
- High oil and grease concentrations can kill vegetation and result in additional pollution.

Operations and Maintenance

Vegetated filter strips may require periodic repair, regrading and/or sediment removal to prevent channelization. Filter strips that are allowed to undergo natural vegetative succession generally require less maintenance. Other filter strips may be managed as a lawn or meadow and require mowing and weed and sediment removal. All filter strips require annual inspections and examination for damage to vegetation, gully erosion or evidence of concentrated flows around the strip.

H. Oil/Grit Separators and Water Quality Inlets

Description

Oil/grit separators (OGS) are typically three-chambered, underground retention systems which remove pollutants from roadways and parking lots. Figure 3-16 presents a schematic representation of an oil/grit separator. The first chamber in the separator/inlet is used for gravity settling of heavy particulates, adsorbed hydrocarbons, and heavy metals; it can also trap floatable oil and debris. The second chamber provides separation by floatation of fresh oil and other emulsified petroleum products. The third chamber houses the storm drain outlet

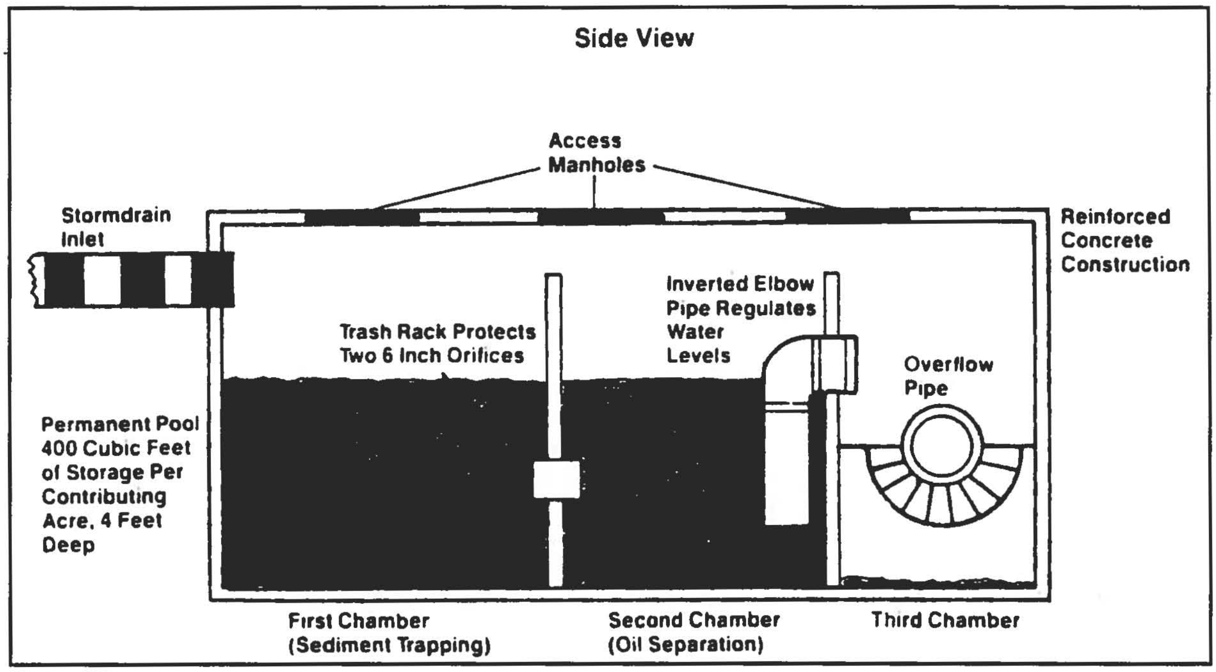


Figure 3-16. Schematic design of a water quality inlet/oil grit separator *Source: Schueler, 1987*

pipe. Manholes are provided for access to each chamber for inspections and cleanouts. In general, pollutant removal effectiveness depends upon basic design configuration, storage volume relative to the watershed size, and maintenance frequency. Use of adsorptive material media within the oil skimming chamber may increase the removal of petroleum hydrocarbons.

Applicability

The use of oil/grit separators is restricted to small, highly impervious basins of about two acres or less and is particularly appropriate for sites expected to receive high amounts of vehicular traffic or petroleum inputs, such as gas stations, roads and loading areas. These urban "hotspots" are known to contribute high concentrations of hydrocarbons and metals to local receiving waters where contaminated sediments deposit on the bottom strata. Oil and grit separators can be used to retrofit parking lots and automotive repair and service establishments at small high traffic sites that do not have room for sedimentation/filtration ponds. They can also be used as pre-treatment for wet storage facilities where visible oil on the surface of the permanent pool may provide poor aesthetics and be detrimental to emergent vegetation.

Effectiveness/Advantages

- Proper facility design, sizing and maintenance is critical for effective constituent capture with this BMP. Studies show dramatic performance differences when design or maintenance are inadequate.
- Limited monitoring data exists regarding the effectiveness of these structures. Although studies show removal performance is often quite limited, inspections of these devices indicate that they do trap sediment, oil, and trash (City of Austin, 1992).

Constraints

- Inflow rates must be limited. The primary technical limitation for oil/grit separators is that inflow rates must be low enough to minimize turbulence and to allow settling and floating of constituents to occur. This is encouraged by limiting the contributing watershed areas (two acres or less) (Schueler, EPA, 1991).
- Studies have shown that, in practice, oil-grit separators are rarely maintained.
- The relative toxicity of OGS pollutant residuals may require special consideration for disposal as hazardous waste.
- Oil/grit separators perform poorly for soluble pollutants.
- OGS performance can be compromised if detergent use in service areas serves to emulsify oils and other hydrocarbons. Pulse hydrocarbon loadings during intense rainfall events is possible due to resuspension of residuals (Shueler et al., 1992).

Operations and Maintenance

Inlets must be cleaned out at least twice a year to dispose of trapped pollutants and ensure proper function (Shueler, 1987). Maintenance may be difficult to coordinate as there is little market for sediment cleanout and disposal services and concerns about the actual or perceived toxicity of the sediments which may make safe, economic disposal difficult (Shueler et al., 1992, Loomis & Associates, 1996).

I. Multi-Chambered Treatment Trains (MCTT)

Description

The Multi-Chambered Treatment Train (MCTT) is a relatively recent, site-level stormwater treatment device developed at the University of Alabama-Birmingham. Figure 3-17 presents a schematic of the MCTT. It offers improved performance as compared to the oil/grit separator. The MCTT is a pre-cast concrete device consisting of three chambers, each of which targets specific components of the toxic load typically generated at urban hotspots. Pollutant

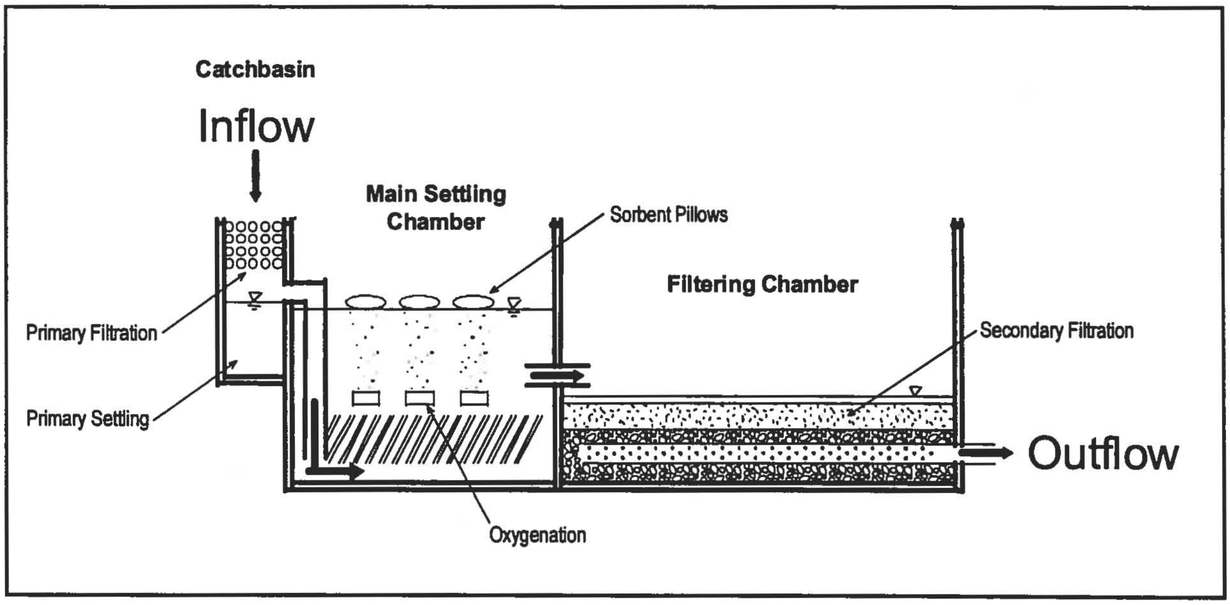


Figure 3-17. Schematic design of a Multi-cham Treatment Train (MCTT) *Source: Loomis & Moore*

removal mechanisms include settling, aeration, absorption, and filtration in a sand/peat media. If developed for general production, the MCTT device would come as a completely contained, prefabricated unit ready for placement at the developed site.

Applicability

The use of an MCTT in a retrofit context is best suited to an area where toxic materials loadings are significant and can be specifically targeted. The MCTT is typically sized to totally contain all of the runoff from a 0.5 inch rain from a typical 0.5-acre gas station. If the area is larger, then multiple or larger units are needed (Robertson et al. 1994).

Effectiveness/Advantages

- As a water quality retrofit strategy, the MCTT may offer excellent pollutant removal performance for a reasonably competitive price. The MCTT has been shown to remove over 75% of most hotspot pollutants, including most toxic organic chemicals, metals, and hydrocarbons (Robertson et al. 1994).

Constraints

- The MCTT is more expensive than an OGS system and requires more space.
- The relative toxicity of MCTT pollutant residuals may require special consideration for disposal as hazardous waste.

Operations and Maintenance

Maintenance requirements for the MCTT include semi-annual clearing of the primary and secondary settling basins, annual replacement or cleaning of the sorbent pillows, and replacement of the sand/peat filter every 3-5 years.

J. Inlet Adsorbents

Description

Inlet adsorbents are a retrofit technique involving placement of adsorbent filters, pillows, sheets or socks in stormwater inlets to remove oil and grease from stormwater before it enters the storm drain system. Installation of some type of oilophilic/hydrophobic material within the inlet chambers reduces the petroleum hydrocarbon component of stormwater runoff that is virtually impossible to remove through settling. A wire mesh or perforated metal basket may be installed to hold the adsorbent material and placed to maximize contact with water entering the inlet.

Applicability

Inlet adsorbents can be installed in conventional stormwater inlets. They are a logical companion to inlet filters (see above). They are only suitable for relatively small drainage areas (less than one acre). To increase contact surface (and thus effectiveness), larger stormwater curb inlets would be needed than are currently in use in Austin (City of Austin, 1992).

Effectiveness/Advantages

- The effectiveness of inlet adsorbents has not been well-documented. Analysis results of a prototype system based on typical oil and grease loading and adsorptive/density properties of adsorbent media indicated that up to 74% of the total runoff can be treated, and more than 74% of the oil and grease in the runoff could be removed if such sorbent filters are installed (City of Austin, 1992).

Constraints

- If not properly maintained, clogging of the inlet adsorbents and impairment of the hydraulic function of the inlet will likely result.
- It is difficult to design an inlet adsorbent system that allows sufficient contact time and contact surface between incoming stormwater and the adsorbent. To have adequate contact time, the drainage area to the inlet would need to be relatively small (less than one acre).
- If concentrations found in stormwater are low or the material is emulsified or attached to particulates, performance may be limited.

Operations and Maintenance

Adsorbent materials must be periodically renewed or replaced. Inlets must be inspected, cleaned out, and sediment and debris removed if clogging is a problem.

3.1.3 Property Acquisition or Enhancement for Water Quality Control

A. Land Acquisition

Description

Land acquisition for water quality protection involves the purchase of strategically sensitive lands. This measure protects raw lands from being developed and therefore maintains low pre-developed pollutant loads in perpetuity. Purchases are made from willing sellers and do not involve condemnation.

Applicability

This option is usually feasible only for undeveloped land. Land characteristics to be considered in the evaluation of a prospective land acquisition project include: (1) degree of long term development pressure; (2) the environmental value of the property including: as a baseflow source, as a buffer for protecting aquifer water quality, as habitat (especially for endangered species), as a park or recreational area, and as a prospective site for future water quality controls; and (3) the owner's willingness to sell.

Effectiveness/Advantages

- Property acquisition virtually eliminates future pollution threat by assuring perpetual maintenance of undeveloped conditions.
- Depending on location, land may provide strategic contiguity, and linkage with other parks, preserves and neighborhoods for hike/bike trails and wildlife habitat.
- Acquired land can provide perpetual recreational and aesthetic benefits such as parkland, preserve, or for other open space uses.
- Perpetually protected land can provide endangered species protection (e.g., the Balcones Canyonlands Preserve).
- Land acquisition can help provide biological resource protection (benefits to priority woodlands, priority prairies, and Critical Environmental Features).

- Acquired land, especially in close contact with sensitive waterways, can assure long term water quality, drinking water, and groundwater supply protection through preservation of the quantity and quality of the baseflow and aquifer recharge systems.

Constraints

- Land acquisition is a costly measure which the public may perceive as having low water quality benefits.
- Land acquisition is generally not a feasible alternative for areas that are already developed due to high costs.
- Cooperation from the property owner is required; desired land may not be available for purchase.

Operations and Maintenance

Land acquired for preservation of environmental resources requires proactive involvement in the long-term management of the property. This can include: (1) habitat and species management; (2) erosion control; (3) vegetation management (see Native Grassland Restoration below); and (4) management of public access (e.g., illegal or unauthorized activities, public education, etc.). In the Austin area, land management cost estimates by various land management agencies included in the Balcones Canyonlands Preserve range from $15 to $80 per acre annually, with the average at approximately $30 to $40 per acre per year.

B. Conservation Easements

Description

Conservation easements for water quality protection are legal agreements with property owners to limit development of properties covered by the easements. The limitation of development greatly diminishes the prospect of future negative impact of the property upon water quality. Development restrictions on a property covered by a conservation easement can range from total purchase of development rights (allowing no further development) to partial purchase of development rights (allowing some degree of low-density development).

Applicability

Conservation easements differ from land acquisition in that the property owner maintains legal possession of the land, while the easement holder acquires the raw land development value. This option is most feasible for undeveloped land, but may be applicable in some situations on land with low-density development.

Characteristics to be considered in the evaluation of a prospective conservation easement project include: (1) degree of long term development pressure; (2) the environmental value of the property including: as a baseflow source; as a buffer for protecting aquifer water quality; and as habitat (especially for endangered species); and (3) the owner's willingness to sell the development rights.

Effectiveness/Advantages

- Conservation easements can provide virtually the same water quality benefits as land purchase options but at a lower cost (roughly 60-80 percent of the purchase value).
- Conservation easement purchase virtually eliminates future pollution threat by assuring perpetual maintenance of undeveloped conditions.

- Depending on location, conservation easement land may provide strategic contiguity with other preserves and wildlife habitat.
- Perpetually protected land can provide endangered species protection (e.g., the Balcones Canyonlands Preserve).
- Conservation easements can help provide biological resource protection (benefits to priority woodlands, priority prairies, and Critical Environmental Features).
- Protected land, especially in close contact with sensitive waterways, can assure long-term water quality, drinking water, and groundwater supply protection through preservation of the quantity and quality of the baseflow and aquifer recharge systems.
- The original function of the land can often continue relatively unaffected, as with ranching.

Constraints

- Conservation easement acquisition is a costly measure which the public may perceive as having low water quality benefits.
- Conservation easements do not generally provide for public access and recreational value.
- Conservation easement purchase is generally not practical for areas with greater than very low-density development.
- Cooperation from the property owner is required.

Operations and Maintenance

The annual costs of the conservation easement option vary depending on the characteristics of the tract (e.g., location, size, etc.) and the ease of cooperation and communication between the landowner and easement holder. Costs vary from approximately $1 per acre annually to approximately the same cost as managing land that is owned outright.

C. Riparian Vegetated Buffers

Description

Riparian vegetated buffers are vegetated lands purchased and set aside in perpetuity along creek channels and waterways. These buffers assist in reducing pollutant loads from developed areas adjacent to creeks. Buffers can function as overbank erosion protection during peak flows and can also serve as a vegetated filter strip for local runoff. They can preclude development in close proximity to waterways, further disconnecting impervious surfaces from direct conveyance to the creek. Degraded or heavily impacted areas may require restoration and replanting to maximize their potential. A native plant or xeriscaped buffer strip minimizes the need for supplemental fertilizer, pesticides, or watering. Buffer areas also provide recreational, aesthetic, erosion control, and wildlife habitat value. They can promote greater public access to and appreciation of creeks and waterways. Figure 3-18 shows the Stacy Park and Blunn Creek Preserve buffer areas which help protect much of the Blunn Creek watershed in Austin.

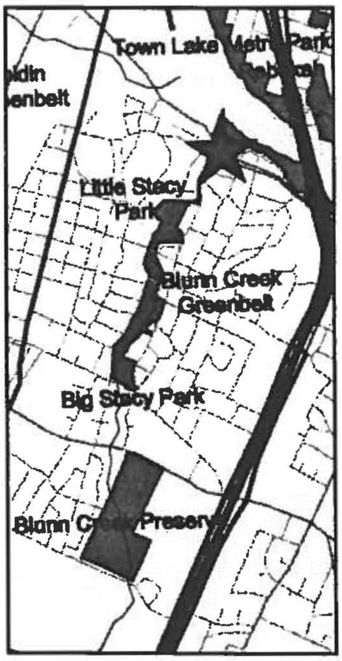


Figure 3-18. Stacey Park/Blunn Creek Greenbelt
Source: City of Austin

Applicability

Riparian buffers are widely applicable as long as suitable, undeveloped lands are available. Riparian buffers are most logically established prior to development to avoid expensive land acquisition or conservation easement costs.

Effectiveness/Advantages

- Riparian buffers are a passive, low-maintenance means of providing habitat, recreational benefit, and aesthetic appeal.
- Although buffer strips along creeks are generally effective at controlling pollution, specific values of pollution reduction or pollution removal are highly dependent on site specific conditions.
- Established vegetation in the overbank promotes slope stabilization. If designed as an erosion control in tandem with biorevetment or as a vegetated filter strip for local runoff, buffer strips can be used to maximize effectiveness of composite sedimentation control strategies.
- Shade trees planted along waterways can moderate water temperatures and improve conditions for aquatic life support.
- Buffers improve property values. Homeowners perceive buffers as attractive amenities to the community (Schueler, 1995).
- A wide stream buffer can include riverine and palustrine wetlands that are frequently found near streams (Schueler, 1995).
- Buffers can provide a foundation for present or future greenways. The linear nature of buffers provides for connected open space, allowing pedestrians and bicycles to move efficiently through a community. Unbroken buffers also provide "highways" for migration of plant and animal populations (Schueler, 1995).
- Buffers can provide space for stormwater ponds. When properly placed, structural BMPs within the buffer can be an ideal location to remove pollutants and control flows from urban areas (Schueler, 1995).

Constraints

- Buffers provide minimal ability to reduce major pollutant sources. Only a small amount of the watershed pollutant load is associated with the near-creek overbank area.
- Buffer zones are difficult to locate in areas where development encroaches closely on the waterway.
- As a retrofit measure, buffer zone establishment may require land owner cooperation for acquisition.
- Heavy recreational use can impair the water quality, erosion control, and habitat value of buffer zones unless continuously maintained.

Operations and Maintenance

Riparian buffers can require maintenance much as do park areas. Buffer strips benefit from the use of native, drought-resistant plant species such that fewer applications of fertilizer, pesticides, and water are needed to maintain an adequate vegetative cover. Use of native xeriscape plants reduces the need for routine mowing, which in turn reduces organic debris loads into receiving waters.

D. Urban Forestry

Description

Urban forestry includes landscaping practices such as the preservation of trees during construction, planting of trees after site clearing, infilling of additional trees on developed sites, and homeowner landscaping after subdivision development. Trees, shrubs and ground cover intercept rainfall and create an organic, permeable layer which promotes infiltration of runoff. Urban forestry is considered to provide limited pollutant removal. Urban forestry does provide shade, scenery, wind breaks, moderation of local air temperatures, and habitat for wildlife. Figure 3-19 depicts a typical urban forestry application.

Applicability

Reforestation or forest preservation measures can be applied to all development areas, both existing and planned. Typically, as much as 50% of a residential lot can be converted into a natural setting of trees, shrubs and ground covers. Trees and shrubs should be chosen based on suitability for site-specific conditions. Reforestation may not be appropriate for areas expected to receive large amounts of foot traffic, such as playgrounds or walkways (Schueler, 1987).

Effectiveness/Advantages

- Urban forestry can help remove pollutants through plant uptake and storage, reduction in runoff volumes, and prevention of soil erosion.
- Shade trees planted in riparian corridors can help shade streams to keep water temperatures, protect aquatic habitat and also stabilize the streambanks against erosion.
- In general, forested areas have been found to produce 30-50% less runoff than grassed areas (Schueler, 1987).

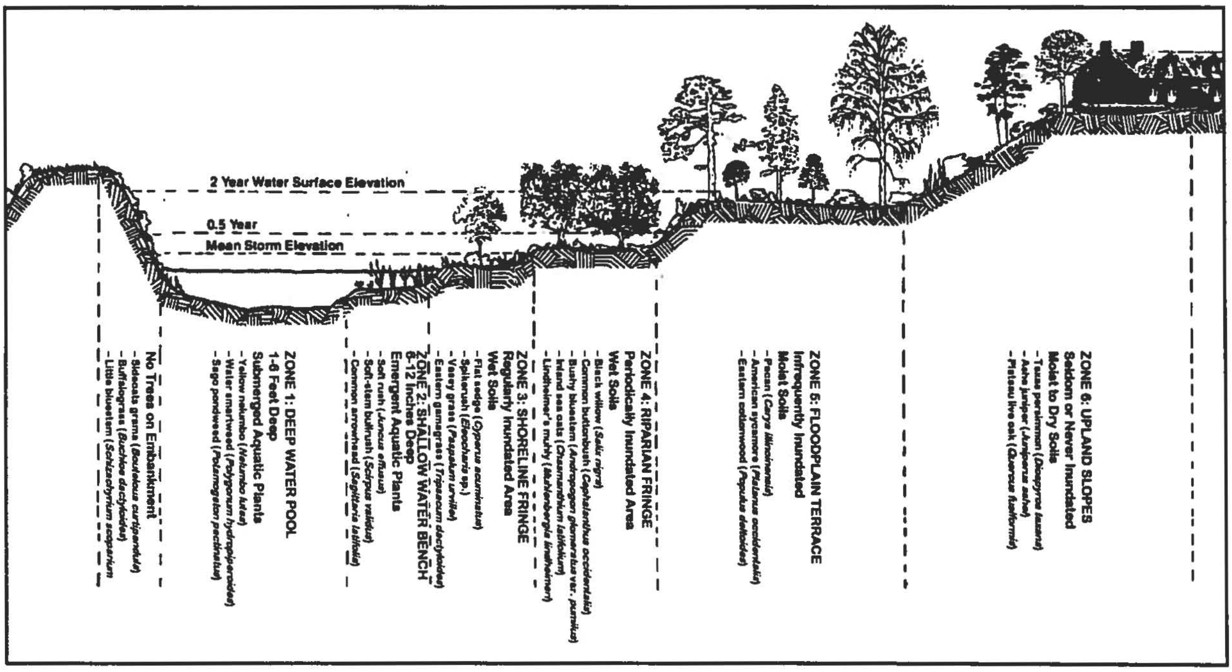


Figure 3-19. Landscaping zones in stormwater areas for consideration in urban forestry *Adapted from Wittans and Weiss, 1985*

Constraints

- Pollutant removal is limited given that the bulk of water pollutants are generated from impervious surfaces, not pervious forested areas.
- The benefits of urban forestry are difficult to measure; it is best considered a component of a larger strategy to limit surface runoff and NPS pollution.
- Heavy recreational use can impair the water quality, erosion control, and habitat value of urban forests unless rigorously maintained.

Operations and Maintenance

Urban forestry requires little maintenance, except during initial establishment and in locations where heavy human activity occurs.

3.1.4 Natural Channel Design

Natural channel design refers to engineered modifications to urbanized stream channels to achieve long-term stabilization of channel form. These designs generally replicate channel forms found in undisturbed natural stream systems, though considerations are made for the greater flow volumes and velocities found in urbanized streams. Natural channel designs include such techniques as width/depth adjustment, terracing, side channels, re-meandering, raising the channel bed to reconnect the floodplain, artificial shoals, and re-creation of pool/riffle systems. These methods can have a very favorable impact on restoring creek systems and improving water quality. Please refer to Erosion Control in this section for a full discussion of these techniques.

3.1.5 Rangeland Management Strategies

Rangelands in central Texas have been traditionally used by ranchers for grazing of cattle, goats, and sheep. They represent the predominant land use in Austin's outlying watersheds to the west. Due to their large areal extent, the condition of these lands may have a significant effect on water quantity and quality. Despite being undeveloped, poor management practices have left much of this area in a deteriorated condition and performing poorly from a hydrologic perspective. Recent research shows that improved management of rangelands can stabilize soils, restore herbaceous vegetation, increase rainfall infiltration, augment creek baseflows, reduce sedimentation and nutrient export, and improve fish and wildlife habitat.

The techniques presented below to improve rangeland pastures are largely contingent upon the cooperation of area ranchers. The City will likely achieve best results by working with these individuals on a voluntary, nonregulatory basis. Examples of successful cooperation exist in Texas; National Resource Conservation Service (NRCS) staff have witnessed an impressive 65-70% participation rate in their voluntary program at the Seco Creek Water Quality Demonstration Project about 50 miles west of San Antonio. Additional nonparticipating ranches have begun to employ the same effective techniques as are being used in the cooperative program. These results, and those seen across the state, show that many ranchers are willing to embrace improved rangeland management, even many who decline formal involvement in publicly-sponsored programs.

A. NATIVE GRASSLAND ESTABLISHMENT

Description

Grassland establishment involves the planting of native bunch grasses in areas invaded by Ashe juniper and other undesirable brush species. Juniper species effect fundamental changes to the local hydrologic system through substantial interception of rainfall, reduction in infiltration (and thus baseflow), and suppression of understory vegetation. Bunch grasses form a thick ground cover and extensive root systems, a combination which serves to impede overland flow, reduce sediment movement, and increase infiltration and resulting creek baseflow. Baseflow enhancement provides increased clean water supplies, aquifer recharge, and recreational benefit. Healthier stands of grass also better sustain livestock.

Applicability

Rangeland grass establishment is generally applicable only for undeveloped ranchlands on the periphery of urbanized Austin. It represents a logical complement to a holistic approach to watershed management; the City may not achieve its water quality goals without addressing the condition of ranchlands which dominate the western suburban and rural watersheds. As Austin grows outward, the opportunity to use restored rangelands as a watershed protection measure will diminish. Over the long run, this option may have to be employed in conjunction with conservation easements, land acquisition, and other measures.

Effectiveness/Advantages

- Native grasslands establishment enhances creek baseflows and recharge to aquifers. Studies in Texas indicate that annual baseflow volumes may be increased by as much as 33% with the removal of juniper and establishment of native grasses at appropriate locations (Loomis & Associates, 1995).
- Due to the vast extent of rangelands in Austin's contributing watersheds, small hydrologic improvement in these areas potentially represent a large-scale solution with large-scale benefits.
- Whereas urban BMPs generally remove pollutants from runoff, restored native grass rangelands lower pollutant concentrations by diluting creek waters with augmented quantities of clean baseflow. Native grasslands establishment can be used to compensate for negative impacts of urban development by improving water quality to a level superior to the baseline condition.
- Establishment of grasslands improves the economic viability of rangelands as pasture for livestock, rewarding the land owner while simultaneously providing watershed protection.
- Native grassland establishment in riparian areas can provide excellent water quality and uplands erosion protection as well as baseflow quantity enhancement. This BMP would be a logical choice in previously denuded areas along streambanks and drainageways. Native bunch grasses are ideal for buffer strips as they have more extensive root systems, encourage infiltration, and physically impede surface runoff. In the Seco Creek Water Quality Demonstration Project, Lometa indiangrass (*Sorghastrum nutans*) filter strips were so effective that runoff, clearly evident on the upslope side of the strips, never managed to travel beyond the strip for measurement, even during heavy rainfall.

Constraints

- Native grasslands establishment is contingent upon the cooperation of rangeland property owners. The City of Austin therefore has little or no direct control over the multitude of land owners who would have to support an effort to implement grassland establishment on a meaningful scale.
- Not all rangelands are suitable for grassland establishment. Many areas with cedar are habitat for the endangered golden-cheeked warbler (*Dendroica chrysoparia*), which the Balcones Canyonlands Preserve seeks to protect. Juniper is a well-adapted native in the Texas Hill Country, and its historic (and more spatially limited) place in steep, rugged, canyons should be preserved. Removal of junipers from these areas could significantly increase erosion and sedimentation. Some flatter, more upland stands of cedar should also be left intact. The selection of areas for grassland establishment should be carefully determined on a site-by-site basis, after conderation of slope, aspect, soil type and erosion condition, geologic substrate, watershed, existing plant community composition, and endangered species occurrence.
- The land for a riparian native grass filter strip must be dedicated and maintained as a water quality control to avoid damage by livestock (see "Control of Livestock in Riparian Areas" below).
- Steeper slopes require wider riparian native grassland buffer strips; very steep slopes preclude the use of this BMP.

Operation & Maintenance

Rangeland clearing to promote bunch grass development must be maintained indefinitely to preserve the positive effects of this strategy. The most cost-effective method to limit juniper regrowth is with the use of "prescribed burns" which employ carefully controlled fires to simultaneously burn away unwanted woody brush (juniper is very vulnerable to fire) and stimulate grass growth. Costs for prescribed burns are low on a per acre basis. If juniper and other woody species are allowed to re-encroach upon the area, the entire area may have to again be cleared (at a significantly higher price).

B. Control of Livestock in Riparian Areas

Description

Riparian areas constitute critical buffer zones for creek protection. Overuse by livestock subjects these areas to damage to the stream channel and to protective riparian vegetation. Cattle and other livestock prefer to remain in close proximity to waterways as they provide drinking water, shade, and locally cooler temperatures. Vulnerable areas along riparian areas can be protected from over-use by livestock using fencing, rotational grazing, and other methods.

Range conservationists disagree on the degree of livestock exclusion necessary in riparian areas. Some advocate complete exclusion using fencing or other equivalent means. Such measures may be necessary in extreme cases, at least for the period of time (often measured in years) needed to allow recuperation or over-grazed riparian vegetation. In less severe cases, range conservationists generally favor controlled access using rotational grazing systems. In this scenario, riparian areas are allowed to rest between grazings while preserving the positive effects of grazing upon grass production. Experts also encourage ranchers to provide alternate sources of water in upland areas (using tanks, troughs, etc.) to encourage livestock to move away from riparian areas and/or to allow the livestock to be temporarily kept in areas without waterways.

Applicability

Control of livestock in riparian areas is widely applicable in ranchlands. Where water supply is limited to creeks needing protection, it may be difficult to both restrict animals from access to the creek and give them drinking water.

Effectiveness/Advantages

- Management strategies limiting continual access to riparian areas have been repeatedly proven effective. Skovlin (1984) cites numerous studies indicating "rather convincing evidence of improved riparian and aquatic environments in a matter of 4-7 years after protection by fencing. Estimates of acceptable shrub recovery vary from 5-8 years in most regions, and fish biomass usually doubled in a matter of 3-5 years. Bird and mammal populations show an equally notable response from heavy grazing release" (cited in Loomis & Associates, 1995).

Constraints

- Land owners working livestock in the Austin area would have to agree to use this management practice. Although beneficial to both land and land owner, this approach requires substantial investments of time (day to day management) and expense (fencing) to implement.
- If creek access is limited by fencing, livestock will have to accommodated with an alternate water supply.

C. Use of Specialized Grazing Systems

Description

Many experts contend that rangelands are best served by management systems which precisely control the number and location of livestock on a given property. Specialized grazing systems include the following:

1. Deferred-Rotation Grazing;
2. Rest-Rotation Grazing;
3. High-Intensity, Low-Frequency Grazing; and
4. Short Duration Grazing.

Traditionally, livestock herds have been maintained at low intensities on a given site for extended periods of time. Such arrangements require minimal management in terms of labor, fencing, and planning. Livestock are allowed to roam freely over a large area; preferred grasses and other forbs are continually browsed without rest. Unfortunately, highly desirable grazing areas, such as riparian zones, are often most heavily used and are not permitted sufficient opportunity to recover. In response, management theories, such as those proposed by advocates of Holistic Resource Management (HRM), maintain that rangelands are best used intensively for short periods with long periods of rest (no grazing). Short duration grazing/HRM advocates maintain that their systems mimic natural patterns of herd animal (ungulates) behavior, thereby stimulating native vegetative systems, which in turn protect soil and water resources.

Applicability

Specialized grazing systems could be used throughout ranching lands in Central Texas. It is likely that over the planning timeframe of the present report (to the year 2040) better information will be available to recommend the best course of action for ranchers. Given the trend toward subdivision of large ranches into smaller rural parcels, it may be necessary for ranchers and other landowners to work collaboratively. With small parcels of land, flexibility is greatly reduced as to where animals can be placed. With larger ranches—or combinations of smaller ranches—livestock can be rotated adequately and the land be allowed to rest.

Effectiveness/Advantages

- The prospects of improving rangeland condition through specialized grazing systems are hotly debated by rangeland conservationists. Some experts maintain that few differences have been found between those lands moderately grazed and those not grazed at all. Some doubt that specialized grazing systems can adequately restore damaged riparian areas. However, most agree that meaningful improvements can be made over traditional practices which pay little attention to the frequency of livestock rotation, especially on marginal or damaged lands so frequently seen in the Hill Country (Loomis & Associates, 1995).

Constraints

- Land owners working livestock in the Austin area would have to agree to use this management practice. Public agencies could provide technical assistance to those landowners interested in these methods.

Operations and Maintenance

Use of specialized grazing systems requires more maintenance and care of animal herds than does traditional ranching and is therefore more expensive. This cost would presumably be borne by the rancher who would have to weigh these costs against the advantages of improved condition of the pasture land.

3.2 FLOOD CONTROL SOLUTIONS

3.2.1 NONSTRUCTURAL FLOOD CONTROL SOLUTIONS

“Nonstructural” flood mitigation strategies are those which do not i
channels, impoundments, levees, or other structural means to redu
late 1960s, U.S. flood control efforts have generally shifted away from “har
tions and toward nonstructural solutions. The Federal Emergency Management Agency (FEMA) has in recent years acted in some cases to remove homes—and even entire communities—from low, flood-prone areas. Nonstructural approaches can also satisfy “multiobjective” floodplain management strategies; the land acquired can be used for public recreation (e.g., parklands, greenbelt areas) and as a natural buffer to protect riparian ecosystems. Nonstructural approaches offer the prospect for integration and fulfillment of all three Watershed Protection missions: flood control, erosion control, and enhancement of water quality; only flood control will be discussed in this section.

Two differing approaches can be used to acquire properties: (1) acquisition using condemnation and (2) voluntary (gradual) buyouts. These two methods differ primarily in the degree of choice given to the homeowners in the area targeted for the buyout. The existence of a choice affects the relative cost of each approach and the degree to which the land purchased can be used publicly.

A. PROPERTY ACQUISITION WITH CONDEMNATION

Description

Property acquisition by condemnation is a process which allows the City to require that all persons and structures be removed and relocated out of the floodplain for reasons of flood safety. The City has the flexibility to define the extent of the area condemned (e.g., the 10-, 25-, or 100-year floodplain). The City uses its power of eminent domain to condemn properties and relocate residents to a safer area. By law, all persons relocated in this manner must be adequately compensated for their property and be relocated to equivalent (or better) housing elsewhere. Both property owners and renters must be accommodated; the City works individually with the families to negotiate a fair price for the property and arrange for acceptable new accommodations for the residents. A “relocation supplement” is paid to owners in addition to the fair market value of their homes (as compensation for the trouble of a forced move), and renters may receive money to cover higher rent payments at their new residence.

With a condemnation buyout, the City does not provide residents with a choice related to vacating the floodplain property. However, the home owner can submit an additional independent appraisal for negotiating purposes. They also have the right to dispute the monetary award which the City offers them in a Commissioners Court established for the purpose. The entire condemnation and relocation process can take many months (or even years) to accomplish, especially in large scale condemnation proceedings.

Applicability

Property acquisition by condemnation has virtually no technical restrictions to its application. It may be used in large or small buyouts. This differs from structural solutions (e.g., detention and channelization) where application can be limited by the presence or absence of a favorable site in which to locate a structure. However, condemnation buyouts do have political and administrative constraints on application: they are difficult to implement where opposed by the neighborhood or businesses targeted for relocation, and the process may take a long time to complete.

Effectiveness/Advantages

- Condemnation offers the City the only means, among the many discussed in this inventory, of completely and permanently evacuating all residents and their property from the target area and out of flood danger.
- Buyouts are a good example of "multi-objective management" strategies for flood mitigation: land set aside for as a floodplain could serve the dual purpose of flood storage and recreational area.
- Unlike structural solutions, creek channels, floodplains, and riparian areas can be left undisturbed or restored using condemnation buyouts.
- Nonstructural buy-out strategies are favored by FEMA and the Corps of Engineers; the City's flood insurance rating could be increased using this strategy.

Constraints

- This approach often has the highest overall cost among all structural and nonstructural approaches although some costs may be offset by matching moneys from state or federal sources. The Corps of Engineers offers financial matches of up to 65% of the project cost, resulting in substantially lower costs for the City.
- There is a high potential for logistical difficulties in negotiation, relocation of residents, and litigation. Contentious and time-consuming negotiations are likely to occur, including possible litigation.
- Forced removal of residents can cause hardships and be politically difficult. Larger scale buyouts can engender more vocal, sustained opposition and greater potential for reduced political will on the part of local authorities.
- A lengthy time is required to implement this approach. In the relatively small condemnation buyouts undertaken in the City's recent Bergstrom Airport and Creekbend projects, the process took over a year.

Operations and Maintenance

The acquired property would have to be maintained by the City; the land could be handled in similar fashion to floodplain lands already owned by the City. Unlike with the structural options, there would not be an engineered solution which would require maintenance and/or replacement to prevent failure and resulting flood loss.

B. PROPERTY ACQUISITION BY PHASED, VOLUNTARY PROPERTY BUY-OUT

Description

In a voluntary buyout, the City gives residents of a target floodplain area the choice to move or to stay. Since no one is forced to move, the City simply pays the "fair market value" for all properties acquired; negotiation expenses are minimized, and relocation and legal expenses are effectively eliminated. Overall costs for this approach are much lower than for its condemnation counterpart. Those residents unhappy with their designation in a floodplain or with the prospect of flooding would be fairly compensated by the City for their homes and presented the opportunity to leave. Those wishing to remain could do so with protection using flood insurance. However, unlike with condemnation, it is unlikely that a targeted floodplain area would be completely cleared of residential structures; therefore some citizens would still remain in harm's way and the City would not be able to use the floodplain for general public use (e.g., as a park or greenbelt). Overall, the voluntary buyout enables the City to demonstrate its good faith in helping citizens with unsellable properties in floodplains while not forcing anyone out against their will.

The process does not require the use of eminent domain, and thereby limits legal expenses associated with condemnation. Since all transactions would be voluntary, the City would not be obliged to purchase any properties it considers too expensive. In general, reduced negotiation costs and lack of contentiousness result in reduced costs to the City. Based upon L&M's discussions with communities with experience with voluntary buyouts (the City of Tulsa and Harris and Montgomery Counties), the estimated cost per structure for a voluntary buyout is about 25 percent above the fair market value of the property (as compared to a 100 percent increase for the condemnation buyout.

Applicability

As with the condemnation acquisition option, voluntary buyouts are widely applicable. Any flooded property could potentially be removed from danger if it qualified for the City's buyout terms. However, political, administrative, and financial realities could serve to limit the application of this approach.

Effectiveness/Advantages

- Residents have the choice to leave or stay. Those unhappy with floodplain designation are provided fair compensation for their homes and the opportunity to leave. Those wishing to remain can do so with protection using flood insurance.
- The cost is lower than for condemnation buy-out. The City can set a limit as to what it can afford.
- There are minimal contentious negotiations and threat of litigation for the City.
- Sales proceed as a normal property transaction. The homeowner (not the City) takes responsibility for relocating.
- Nonstructural buy-out strategies are favored by FEMA and the Corps of Engineers; the City's flood insurance rating could be increased using this strategy. Voluntary buyouts are potentially eligible for modest FEMA funding assistance.
- Unlike with structural solutions, creek channels, floodplains, and riparian areas can be left undisturbed or restored using condemnation buyouts.

Constraints

- Floodplain reclamation is gradual until a large flood occurs. Residents who choose to stay remain in "harm's way" in the floodplain.
- Residents of lower-valued properties, especially those on fixed incomes, may not feel they have the choice to leave. This disadvantage could be addressed in the design of the program, though issues of cost, fairness, equity, etc. would also have to be addressed.
- Gradual elimination of homes could have a negative impact on the remaining community. The neighborhood would be subjected to a "missing tooth" process as structures are removed in a random and non-contiguous manner.
- Vacant lots will require ongoing City maintenance in a residential setting. The City, as owner, would bear long-term responsibility for removing all structures and maintaining the grounds.
- Land purchased by the City would not likely be contiguous, and therefore less suitable for general public park use for the short-term.
- The gradual nature of the program requires a longer-term obligation for the City; a full buy-out is likely to take many years.

Operations and Maintenance

The acquired property would have to be maintained by the City; the land could be handled in similar fashion to floodplain lands already owned by the City. Unlike with structural options, there would not be an engineered solution which would require maintenance and/or replacement to prevent failure and resulting flood loss.

3.2.2 Structural Flood Control Solutions

Structural solutions are engineered modifications to the hydrologic or hydraulic regimen of waterways which reduce flood risk. Unlike buyouts, they offer a means of allowing development to remain in place. They can be used in combination with nonstructural buyout strategies to gain a lowest cost solution to a flooding problem.

A. Flood Detention

Description

Detention ponds are impoundment structures which capture and detain storm runoff. They are designed to store flows during the most critical part of the flood and release the stored runoff volume as the flood subsides. While detention does not reduce the total volume of runoff from a flood event, it serves to reduce the peak flow rate, thereby lowering water depths and reducing flood risks downstream.

The principal design considerations for detention ponds are storage volume and the hydraulic character of inlet and outlet structures. The inlet serves as a means for receiving and regulating stormwater inflow. Inlet structures can be designed to accept water during various stages of a storm event. The flood storage volume area is usually constructed by enclosing an open area with earthen berms or structural walls. In some cases, high land values makes it more cost effective to construct an underground storage volume with buried pipes, specially designed stackable devices, or some other underground cavity.

The outlet structure controls the outflow rate. The storage volume must be large enough to store the volume difference between the inflow and outflow hydrographs; otherwise, the flood peak will overtop the detention pond.

There are two basic configurations for detention ponds: on-line and off-line. On-line detention ponds are positioned directly in the channel with both low and high flows passing through the facility. Figure 3-20a presents a photograph of a typical on-line detention facility. Off-line detention ponds are located to the side of waterways. They remain empty until flood flows reach a certain level, whereupon excess flood flows are diverted from the normal flow path into the detention pond. After the flood flow recedes, the storage volume spills back to the main flow path. Figure 3-20b presents a photograph of the Northwest Park off-line detention facility.

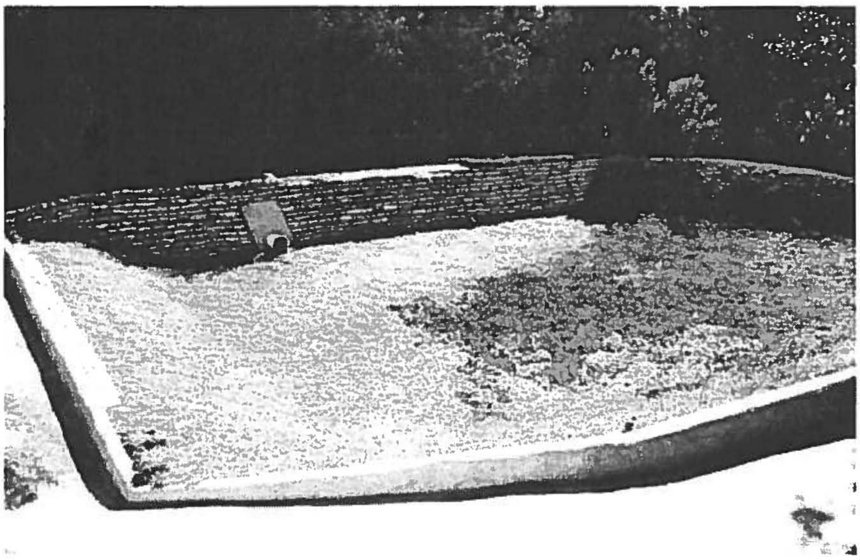


Figure 3-20a. Typical office building on-line flood detention facility near RR 2222
Source: Loomis & Moore

Figure 3-20b. Inflow wall for off-line flood detention facility at Northwest Park
Source: Loomis & Moore

Applicability

The scale of application ranges from numerous small ponds throughout a watershed to large regional ponds. Typically, large regional detention facilities are more efficient than numerous small facilities and are less costly to maintain. The primary resource requirement is available land. As a result, this solution type is more difficult to apply in highly urbanized areas where open space is limited and land values are high. Detention ponds find easier application in suburban areas with greater land availability.

Effectiveness/Advantages

- Detention ponds provide flood control by reducing peak flows and thereby lowering stream flood stage. Detention provides erosion control by reducing peak flows, though the design requirements for erosion control may differ from those of flood control. Older ponds may be retrofit to be more effective for erosion control by redesigning the inflow or outflow structures and by increasing the storage volume.
- The straightforward concept of reducing peak flows is highly effective and used worldwide for flood control. There is little that can go wrong with a facility in proper structural condition. Timely maintenance is important.
- Detention ponds can be designed as "dual use" facilities for park and recreational use as well as flood control.
- When attractively incorporated into the landscape, detention facilities are well-accepted by the public. Regional detention facilities used as parks or athletic fields are generally popular, while less aesthetic or poorly maintained facilities may suffer low public acceptance.

Constraints

- Detention ponds require large areas for effective detention. Retrofitting is difficult in urbanized areas where the need for flood control may be greatest.
- Available pond locations may be counterproductive for flood control. Detention may be detrimental to flood control when placed in the lower portion of the watershed. In locations where runoff would pass through the stream network before the upstream peak flow arrives, detention may delay the local peak to coincide with the upstream peak and increase the overall watershed peak, raising water surface elevations and flooding.
- If detention disrupts the natural movement of sediment through a reach, the change in sediment concentration may upset the stream equilibrium and create new erosion downstream. In such locations, an off-line configuration may be used to avoid disruption of bed load movement.
- The trailing leg of the effluent hydrograph is flattened and extended as a result of flood detention storage. Multiple applications of flood detention at varying locations in a watershed can result in negative flood impacts through accumulation of trailing leg flows. Recognition and avoidance of this effect is possible through basinwide planning and hydrologic modeling.

Operations and Maintenance

Grass-lined facilities require regular mowing, and structures with small outlets or standpipe outlets may require trash or debris removal. Sediment must be periodically removed to ensure that the facility retains its original design volume. Inspection of inflow and outflow structures is necessary to assure continued structural integrity.

B. CHANNELIZATION

Description

Channelization consists of modification of an existing channel or excavation of a new channel. The second option is discussed in Flow Diversion: Channels and Tunnels. Channelization has traditionally been used to increase flow capacity (conveyance) by changing the existing channel geometry. This allows runoff to be more efficiently conveyed during storm events, thereby reducing water depths and the potential for flooding. Figure 3-21 presents a photograph of a channelization project on Shoal Creek.

Channel flow capacity (conveyance) is increased by one or more of the following:

- enlargement of the channel flow area;
- reduction of channel/floodplain roughness or flow impediments;
- shortening of the channel flow path; and
- increase in channel slope.

Applicability

Channelization is a common and long-used method for flood control. It can be used to alleviate most flooding situations; however, the use of channelization has been curtailed in recent years due to potentially negative impacts upon erosion control, water quality, and stream aesthetics.

Effectiveness/Advantages

- Channelization operates on simple and reliable physical processes: increased conveyance yields reduced water surface elevations for a given flow rate.
- Channelization is often the only option to reduce flood risk without moving people or structures. It may be fit into urbanized areas for flood relief where detention and property acquisition are impossible or cost-prohibitive.

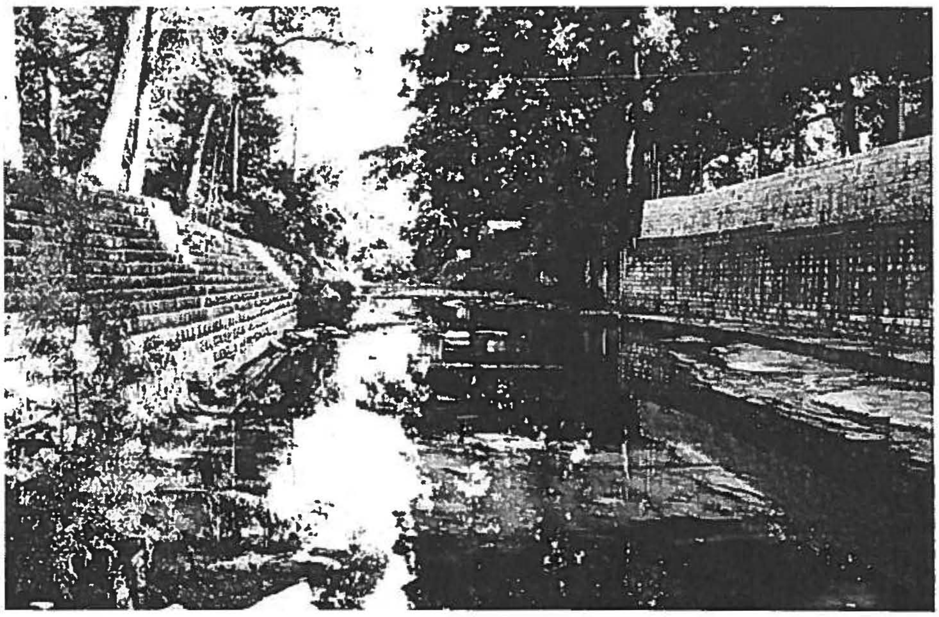


Figure 3-21. Flood channelization on Shoal Creek at Hunt Trail *Source: Loomis & Moore*

Constraints

- Channelization can fundamentally disrupt natural stream processes. Widened channels eliminate established vegetated riparian areas. Higher flow velocities can cause bank and channel scour, discourage downstream vegetation establishment, and destroy plant and animal habitat. Optimal channel configurations for increasing conveyance and the use of associated structural revetment are typically not "natural" or aesthetic.
- By reducing flood storage and moving water more quickly through a problem area, peak flow rates are increased and flooding problems may be created downstream.
- Channelization often uses gabions, concrete riprap, or the equivalent to armor the channel; these treatments can themselves be undermined and destroyed by creek flows. Channelization benefits may also be lost if sediment depositions are not removed periodically to ensure the solution operates as originally designed.
- Channelization can require a substantial physical space for proper design and flow conveyance. This may require removal of structures in the riparian zone.

Operations and Maintenance

Channelization generally requires minimal inspection and maintenance except in conjunction with erosion of revetment structures and vegetation management targeting channel friction increases.

C. Structure Raising

Description

Structure raising physically removes threatened structures from the floodplain using fill material or some form of piers, posts or columns. Figure 3-22 illustrates one form of structure raising. Typically, steps necessary to elevate a building include: inserting a cradle of steel beams under the structure, using jacks to raise both the beams and structure to the desired height, construction of a new elevated foundation for the home, then lowering of the structure onto its new foundation to be reconnected (FEMA 1986). In some cases, City of Austin 25-year floodplain restrictions may disallow the use of fill materials if they impair floodplain conveyance. The implementation of piers, posts, or columns will likely result in marginally increased floodplain conveyance (with the home removed as an obstruction) and reduced flood elevations.

Applicability

From a technical standpoint, most structures can be elevated out of floodplains: it is possible to raise buildings as much as 20-feet off the ground. However, from cost, physical access, and aesthetic standpoints, more modest elevations are likely in order. If the flood elevation is greater than 4-feet above the grade, steps must be taken to keep the house in livable condition and restore the surrounding site. Raising the elevation less than 4-feet normally has little effect on the appearance of the house and restoration work can be minimized (grading, landscaping, etc.).

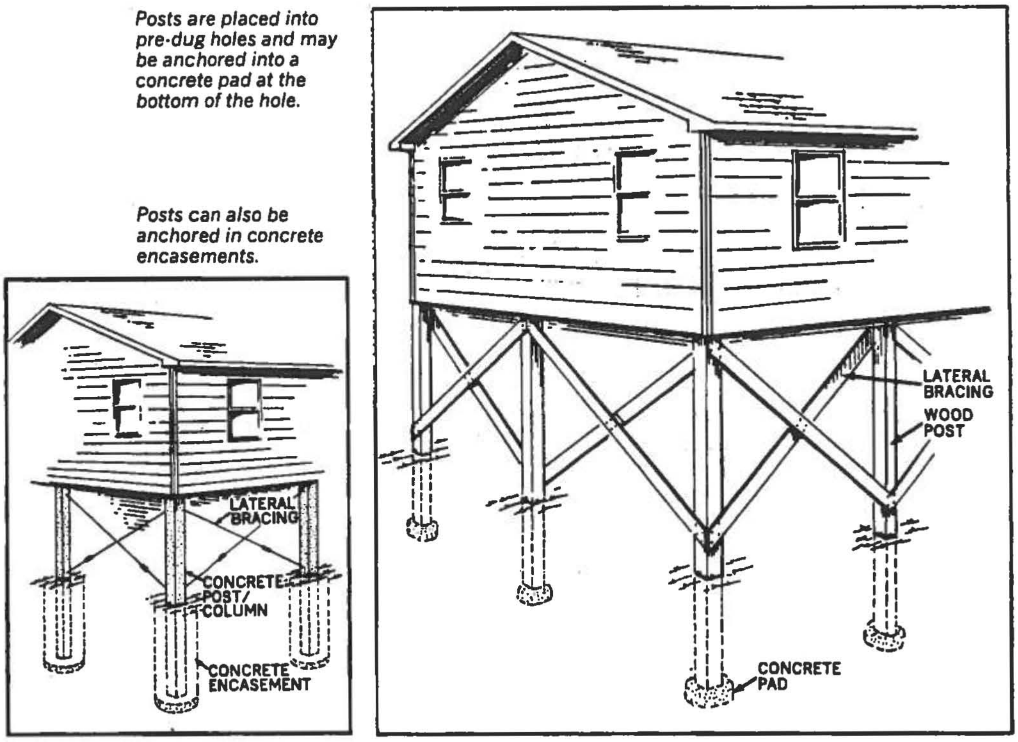


Figure 3-22. Schematic design for structure raising *Source: FEMA, 1986*

Effectiveness/Advantages

- Structure raising is an effective means of removing threatened buildings from floodplains. However, constraints on safety, access, and aesthetics may dampen enthusiasm for this option.
- Structure raising allows structures and their occupants to remain on their site rather than be removed or destroyed.

Constraints

- Emergency vehicles may still be blocked from reaching occupants in raised structures, and occupants may be not be able to escape while flood waters remain high.
- While raised structures may be out of danger, other valuable property and infrastructure (roads, utilities, vehicles, landscaping, etc.) may still be destroyed. Significant clean-up will still be necessary after larger floods.
- Elevating the structure may require a change in the method of access to the home, normally including the construction of exterior and/or interior stairways. These new access structures may not be desirable for some residents who may find it difficult to manage a longer climb to their home during daily activities.
- Raising structures may cause a severe alteration in the aesthetic character of the neighborhood.
- Property values may be lowered in proportion to aesthetic, safety, and access concerns.
- Not all structures can be reasonably raised. Structures difficult to raise include: houses over basements, houses with no crawl space or basement, slab-on-grade construction, houses made with heavy building materials or complex design, or homes with building additions.

Operations and Maintenance

Maintenance of the raised structures would be the responsibility of the property owner. However, the City may choose to inspect the floodplain to ensure that structures have been properly removed from danger.

D. Storm Sewer Upgrades

Description

Storm sewer upgrades consist of either replacement or renovation of the existing storm sewer system. This flood mitigation approach generally targets localized nuisance flooding caused by inadequate size or structural degradation of an existing system. It is usually performed in response to direct storm sewer inspections, citizen complaints, and/or updated hydraulic modeling of the system.

Applicability

Storm sewer replacement or upgrades can be expensive. Therefore, this approach is generally used on an "as-needed" basis in locations where nuisance flooding and public complaints are frequent. All storm sewers must eventually be replaced, thus upgrades for storm sewers that are not considered a problem by the public should be performed as part of a long-term and well-planned, systematic replacement program.

Effectiveness/Advantages

- In conjunction with a regular inspections and maintenance program, renovated or upsized storm sewers design and construction is effective and reliable. Properly constructed and maintained storm sewer systems can last many generations.

Constraints

- Storm sewer renovation costs may be expensive compared to the flood benefit gained.
- Storm sewers designed decades ago often do not meet current conveyance criteria. In conjunction with structural degradation and/or maintenance neglect, large portions of a municipal storm sewer system may come to be considered undersized and thereby candidate for expensive renovations. Despite technical confirmation that a system is substandard, the decision to perform expensive storm sewer renovations should perhaps be dictated by public perception of a problem.

Operations and Maintenance

In many cases, relatively simple problems such as clogging or localized structural deficiencies are causing frequent nuisance flooding. A regular operations and maintenance program is critical to alleviating simple problems and to determining the appropriate level and cost for remediation of more serious problems.

E. Flow Diversion: Channels and Tunnels

Description

Flow diversion involves directing a portion of the flood peak to an alternate flow path. Options include channels or pipe conduits. Where the existing channel conveyance in insufficient, excess flows can be carried either along an open channel diversion or closed pipe (tunnel) conduit path. The diversion may rejoin its original channel or proceed to a different location.

Flow diversion may be accomplished online or offline. Offline systems pass all flow through the original path until a certain flood elevation is reached and a control diverts additional flow to the diversion path. Online systems divide flow between two paths throughout the range of flood stages. Figures 3-23a & 23b present schematic representations of the proposed Waller Creek tunnel.

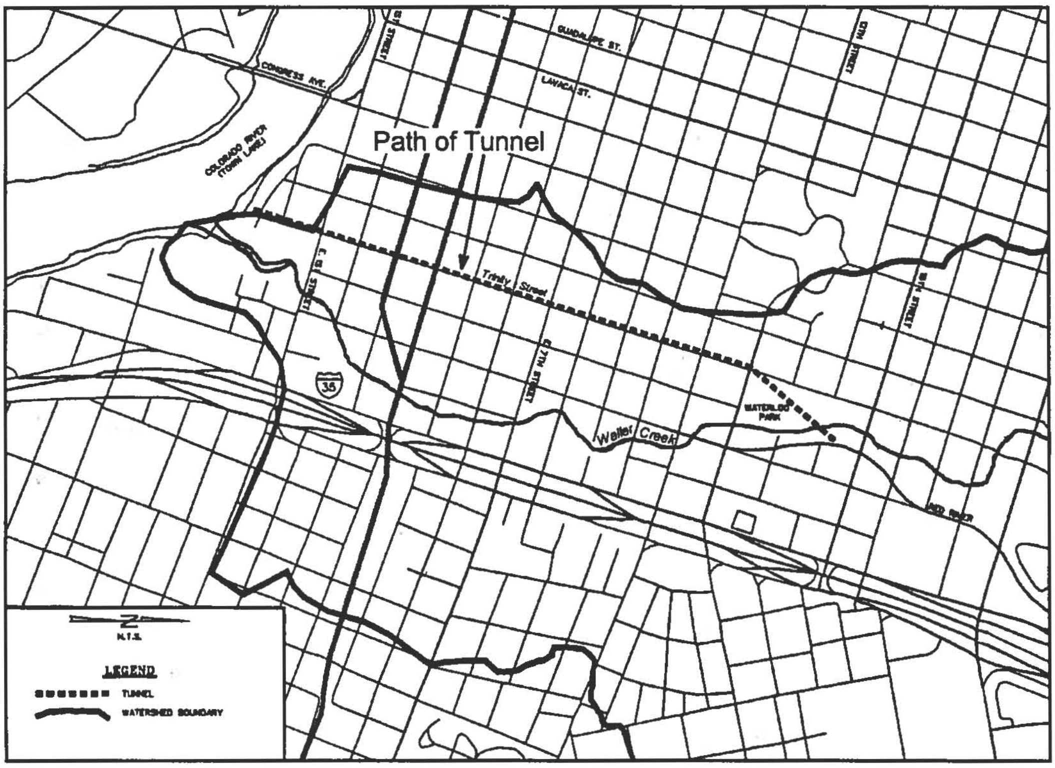


Figure 3-23a. Schematic of Waller Creek tunnel path

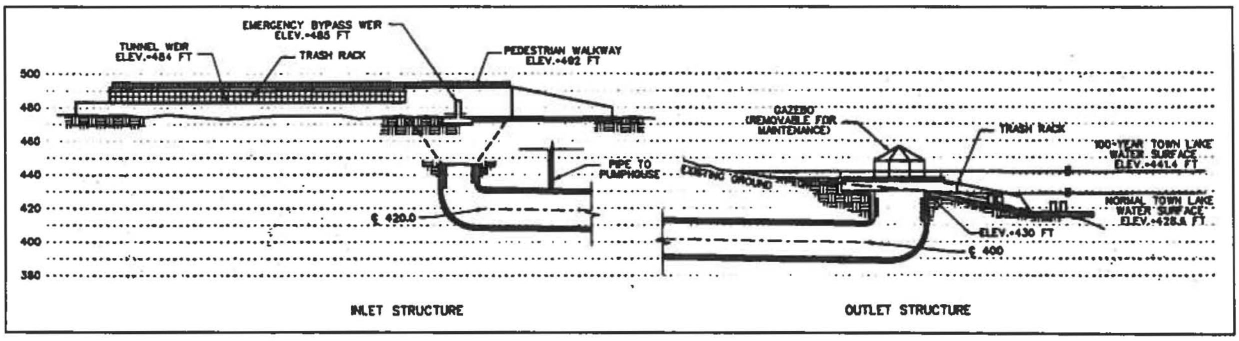


Figure 3-23b. Cross-section of Waller Creek tunnel

Applicability

Typically, flow diversion using a channel is applicable only when sufficient space is available in the overall flood conveyance path. Diversion tunnels are used where space is limited as they can be built deep below the ground surface. Diversion tunnel construction is expensive and thus may be feasible only where the recovered property has high economic value or there is substantial flood threat and no other available alternatives.

Effectiveness/Advantages

- Virtually any form of diversion which increases total flood conveyance at a flood problem area will reliably reduce water surface elevations along the original flow path. Land which formerly served as overbank conveyance may be reclaimed and used for other purposes.
- Significant erosion benefits may be realized where a stream is stable for low flow events but unstable for extreme events. For this situation diversion of the extreme events can eliminate erosion problems along the original flow path.

Constraints

- Flow diversion is often the selected solution when all other, less expensive and more conventional solution strategies have been discarded. The Waller Creek flood diversion tunnel, for example, was selected as the appropriate solution in lieu of channel improvements, which were considered excessively destructive in the highly developed downtown, and regional detention, which is limited in its effectiveness by lack of undeveloped space in the upper portions of the basin.
- It is rare that space for an alternate surface flow path is available in an urbanized flood problem area. The selection of this solution type may therefore be dictated by the chance availability of an appropriate alternative conveyance path.
- Excavation of a new, alternative flow conveyance path can result in substantial damage to existing riparian vegetation and habitat.

Operations and Maintenance

Vegetative control maintenance requirements in rarely-used diversion channels can exceed those for the main drainageway if normal scouring processes are not present and vegetation is allowed to thrive in the diversion channel's primary conveyance path. The primary operations and maintenance concerns for tunnel diversion structures are: (1) removal of trash and debris from the trash rack at the inflow structure; and (2) periodic removal of settled solids captured in the tunnel.

F. Replacement of Structural Constrictions

Description

Culverts, bridges, low water crossings, and other structures often create local constrictions in streams. For a variety of reasons (changing watershed conditions, inadequate design criteria, poor design methods), the originally designed conveyance through these structures is not adequate and head losses associated with the constriction cause increased flooding upstream. Replacing undersized structures or removing constrictions reduces upstream water surface elevations by reducing head losses through the constricted area. Inadequate structures may be removed or replaced by larger structures. Unneeded structures may be replaced by a riffle. A low water crossing may be replaced or modified to serve as a check dam with a protected stilling basin. To preserve the obstruction, a bypass channel with riffle may be warranted.

Applicability

This solution is best applied where a stable channel provides adequate conveyance but a structure constriction is creating localized flooding and/or scour. Channel movement in an unstable creek often requires structure replacement in conjunction with channelization or bank protection.

Effectiveness/Advantages

- A single, localized constriction can cause significant head losses and upstream increases in water surface elevation. Substantial and potentially inexpensive flood relief may be realized through removal (and sometimes redesign) of the constriction.
- High velocities associated with turbulence and critical flow can undermine abutments or piers, and degrade channel bottoms or culvert outlets. Overtopping of existing structures can wash out sections of road or scour the outside edges of abutments. Replacing undersized structures mitigates scour and prevents structure failure.

Constraints

- Because a stream constriction creates backwater, the upstream channel segment may experience new erosion problems after constriction removal due to higher flow velocities and channel shear stresses.
- When the constriction is a functioning hydraulic structure such as a bridge, replacement costs can be high for relatively minimal flood relief.

Operations and Maintenance

Until the channel is stable, periodic inspection of the project site is necessary to assure that the new hydraulic conditions have not resulted in new erosion problems.

G. Levees and Floodwalls

Description

Levees and floodwalls are linear, man-made barriers which prevent flood flows from accessing flood-vulnerable areas. Figure 3-24 presents a photograph of levee application for a single residential structure. Levees are generally constructed of compacted soils and take up a large amount of space as a result of the relatively gentle embankment slopes (typically 3:1) required for stability. Consequently, levee heights are often only 10 to 20 percent of the corresponding base width. Levees are generally constructed using low permeability soils with individually-compacted 6" lifts.

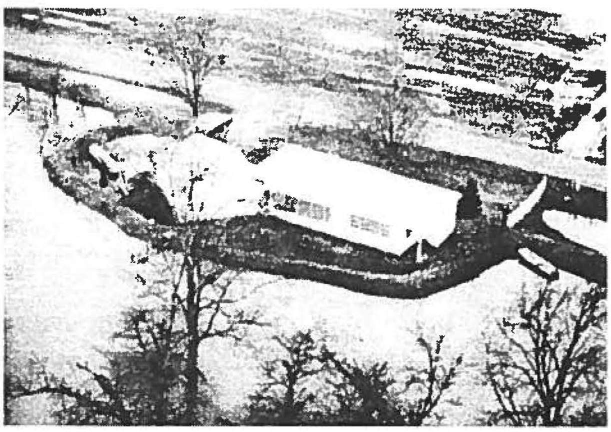


Figure 3-24. Levee *Source: FEMA, 1986*

Floodwalls are generally constructed using masonry block and poured concrete. The potential for significant hydrostatic pressures requires significant lateral footings and steel reinforcement. Floodwall construction in areas with permeable soils also requires deep footings to prevent substructure erosion and failure.

Applicability

Levees and floodwalls are most applicable where floodwaters encroach upon structures but the overbank region is not required for local conveyance. To the extent that levees constrict conveyance to the main channel, flood storage volume is lost (resulting in peak flow increases downstream) and channel velocities are increased (resulting in greater erosion potential). Locations requiring shorter walls (2 to 5 feet) are most practical due to difficulties associated with obstruction of drainage, roads, and/or utilities.

Effectiveness/Advantages

- If properly designed and constructed, this technology provides reliable, predictable and effective flood protection.

Constraints

- During extreme events which exceed the design conveyance of the levee or floodwall system, flood protection failure may be sudden and catastrophic.
- Levee construction in the floodplain results in loss of overbank storage during extreme events and increased downstream flow rates. This impact can be significant in areas with widespread levee application (as on the Mississippi River upstream of St. Louis).
- Sufficient storage volume must be available to store runoff flows captured behind the levee or floodwall during flood events.
- If greater than just a few feet in height, levees and floodwalls can have a substantial negative aesthetic impact and will result in reduced access to the waterway.
- Construction of levees exceeding a few feet in height can result in significant loss of native riparian vegetation and habitat.
- Older levee/floodwall systems which have not been maintained may be structurally vulnerable to design hydrostatic pressures.

Operations and Maintenance

Although entirely passive in operation, this flood control approach requires a significant commitment to inspection and maintenance. Weakened levees can fail prior to design hydrostatic pressure resulting in substantial risk to life and property. Maintenance issues for earthen levees include erosion and vegetative encroachment on the structure. Floodwalls must be checked for cracks, erosion, and footing stability.

3.3 EROSION CONTROLS

3.3.1 PROPERTY ACQUISITION FOR EROSION CONTROL

Description

Properties and structures vulnerable to erosion may be removed from threat through direct acquisition of land or structures in the problem area. As with flood control, erosion control acquisitions can be made (1) using condemnation or (2) with the voluntary cooperation of the landowner. See the above section on "Nonstructural Solutions for Flood Control" for a full description of property and structures acquisition procedures.

3.3.2 SIDE SLOPE TREATMENTS: BANK PROTECTION/ REHABILITATION

Side slope treatments are techniques which directly reinforce or armor channel banks for stabilization and erosion control. They are typically used to prevent the loss of property (houses, roads, parklands, etc.) to bank erosion. They range from vegetative revetment to concrete coverings and can be applied along an entire length of channel or at isolated trouble spots. They are useful for addressing existing erosion problems. Where future problems are anticipated (due to upstream development, for example), other measures may be necessary to manage peak flow rates and high flow durations.

Any bank protection schemes must be considered in light of predicted future channel morphology and migration. Localized stabilization of an unstable channel system can result in failure of the site-specific erosion control measure. Where storm flows are projected to increase substantially in the future, bank stabilization should be combined with detention, channelization, and other techniques at the watershed level.

As a general rule, the toe of bank or other high shear stress areas require a hard reinforcement such as rocks or gabions. Banks can often be stabilized with softer reinforcements such as vegetation or reinforced earth. The goal for bank stabilization is to establish a long-term equilibrium for erosion control such that future bank rehabilitation is not necessary. In the short-term, some bank stabilization solutions may require extensive earthwork and the destruction of trees and riparian vegetation to achieve this goal.

Patching banks with concrete rip-rap or stone gabions can engender further streambank erosion by increasing stream flow velocities to unprotected downstream segments. Furthermore, strong currents often undercut the upstream and downstream ends of rip-rap and gabion structures. If the concrete apron is extended to repair this undercutting process, a recurring cycle of patching and undercutting can be promoted leading to the loss of additional natural stream bank with each repair.

A. Reinforced Earth

Description

Reinforced earth is a slope stabilization and vegetated channel revetment technique. Slope stabilization is provided through incremental placement of soil lifts reinforced by layers of geotextile fabric between each soil lift. The slope facing can be vegetated. This approach is distinguished from other biorevetment techniques in that it can be structurally stable at slopes as steep as 0.5:1. Figure 3-25 presents a typical reinforced earth design.

Applicability

Reinforced earth can be used within confined channel systems where slopes are steep and the ability to lay back the slopes is limited. Applications include: (1) narrow, deep channels (confined channel systems); (2) parkland; (3) in conjunction with natural channel design approaches; (4) to protect structures and roadways along the channel; (5) in high velocity and high shear stress streams; and (6) on severe channel bends in conjunction with appropriate toe protection. This technology typically requires toe protection for application on the outside of channel meanders.

Effectiveness/Advantages

- Reinforced earth has many of the natural channel and aesthetic advantages of engineered biorevetment techniques, but can accommodate steep side slopes (0.5H:1V).
- This technology can withstand long durations of high flow, high velocity, and significant shear stresses.
- Reinforced earth has a natural appearance when the vegetation becomes established.
- This approach is generally lower in cost than other structurally stable channel revetment techniques (i.e., gabions, concrete walls, and concrete riprap).

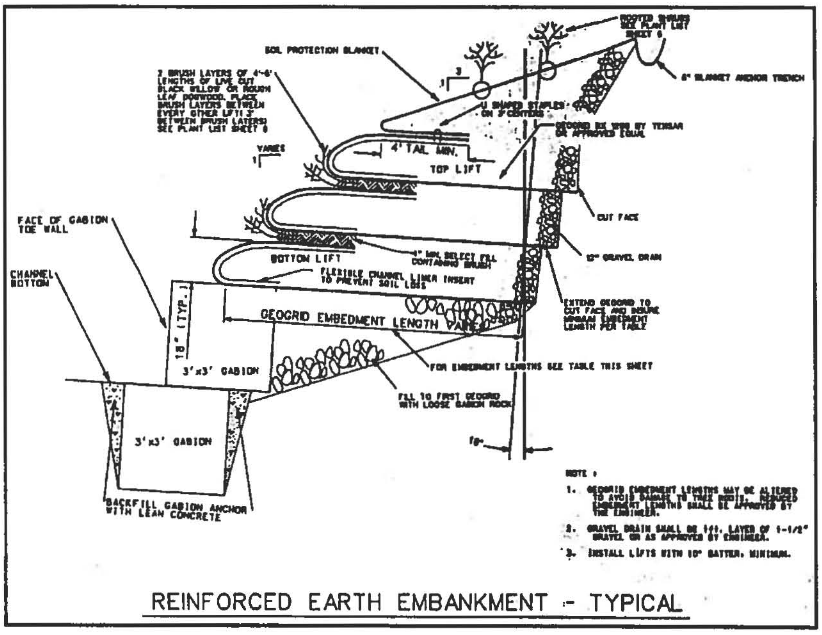


Figure 3-25. Schematic for reinforced earth *Source: City of Austin*

- Due to the vegetative facing, reinforced earth does not necessarily increase channel velocities (unlike concrete slope paving).
- Reinforced earth can provide wildlife habitat.
- This method is relatively vandal proof, with virtually no potential for graffiti.
- Large-scale reinforced earth construction projects can result in substantial loss of existing riparian vegetation.

Constraints

- Reinforced earth can not be used in vertical channels requiring some degree of slope for stability.
- In some cases, specialized groundwater drainage systems are required to maintain slope stability.
- Presently, only a few contractors in the Austin region have construction experience with this technology which may adversely impact project cost and quality.

Operations and Maintenance

Reinforced earth requires vegetation control and possible weeding during the first years following project implementation to ensure survival of desired species.

B. Vegetative Bioengineering

Description

Bioengineering uses vegetative plantings, together with more traditional engineering techniques, to stabilize stream banks and embankments. Figure 3-26 shows three stages of a typical bioengineering application. Living plant materials are introduced into soil backfills and slopes to provide erosion resistance, strength and support from the plant root network. These techniques have been used in Europe since early in the twentieth century and in the U.S. during the last few decades. Specific techniques include "live staking" (driving dormant tree stakes and posts into the bank to take root), "wattling" (laying dormant brush horizontally in trenches behind batter boards up the sides of an embankment), and "contour brush layering" (placing dormant shoots into reinforced soil layers which are terraced up the bank) (City of Austin, 1992). The plant communities are selected for extensive root systems, resiliency to flows and inundation, and capacity of self-support and self-repair. Plant survival is crucial to the survival of the surface coverage.

Applicability

Bioengineering is broadly applicable to unprotected, stable soil embankments. Bioengineering can withstand stream flow velocities greater than grass-lined channels. An analysis must be performed to ensure that the introduction of the new plants does not obstruct stormflows to the extent that they cause flooding. Maximum effectiveness is sometimes achieved by using a combination of bioengineering and conventional engineering. For example, bioengineering can include large rocks to reinforce high shear stress points at the bank toe or a combination of riprap interspersed with vegetation. However, bioengineering lacks the structural component of reinforced earth and can not be used in steep channels with high bank slope.

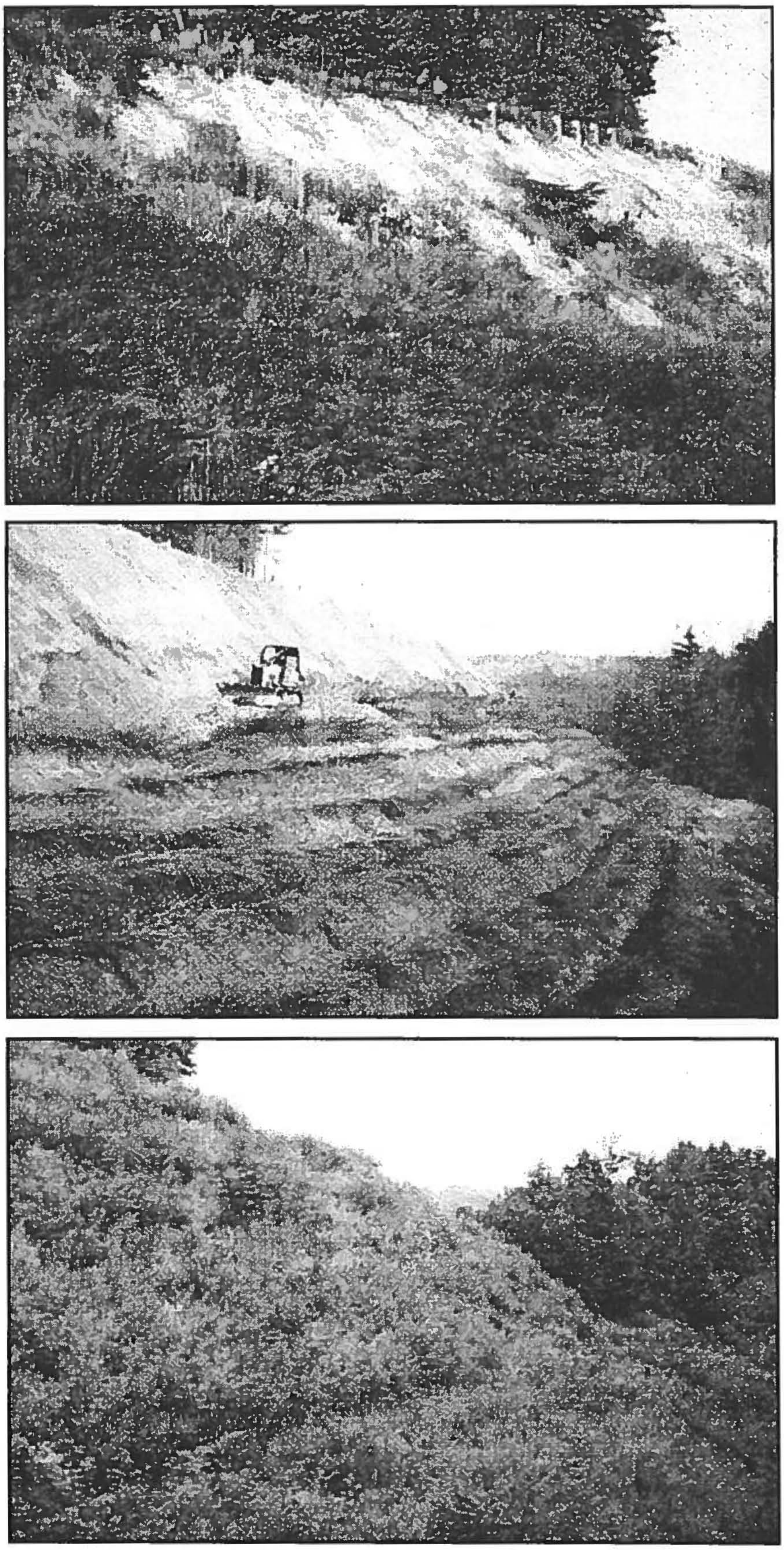


Figure 3-26. Stages of bioengineering Source: USDA, 1992

Effectiveness/Advantages

- Bioengineering has proved to be an effective, permanent, and environmentally responsible alternative to conventional erosion control techniques. The Town Lake Study concluded that bioengineering techniques would be "highly effective" in controlling sediment loads to Town Lake (COA, 1992).
- Stream channel aesthetics are effectively preserved (particularly important since many erosion sites are in streamside parks).
- This technology can be especially appropriate in creeks which have long stretches of eroding banks. Austin's pilot project on Little Walnut Creek has proven the effectiveness of this alternative with reduced channel maintenance and good public acceptance.
- The Little Walnut Creek bioengineering pilot project exhibited construction costs lower than gabions and concrete.
- This approach can be used effectively in the natural channel design process.
- Bioengineering provides relatively high, natural channel friction, thus moderation of post-channel improvements flow velocities.

Constraints

- Application is limited to relatively shallow side slopes (approximately 2H:1V).
- Large scale construction due to shallow slopes can require the elimination of existing vegetation.
- Presently, few contractors have construction experience in this technique which may adversely impact project cost and quality.
- The aesthetics of bioengineering may not appeal to all. Some citizens, concerned about safety and rodent control, object to growing "weeds" in creekbeds adjacent to their back yards. Some people prefer the appearance of concrete rip-rap or gabions to plants.
- Hazards exist during initial establishment. Flooding during the initial stage of a bioengineering project may result in partial or total loss of plant and soil materials which would aggravate sediment and debris problems as well as having localized adverse impacts in the creek.
- This approach requires toe protection if used on the outside of channel meanders.
- Bioengineering potentially causes flooding problems due to increased floodplain roughness.

Operations and Maintenance

Once bioengineered installations are successfully established, maintenance costs are moderate. Selective vegetation control following construction is necessary to ensure the survival of desired plants. The maintenance costs associated with the undercutting of rip-rap and gabion structures is usually eliminated with bioengineered slope treatments. Bioengineered slopes will likely have a longer service life than conventional slope treatments and are, to some extent, self-repairing.

C. Vegetation Reinforcement Techniques

Description

Vegetation reinforcement refers to the engineered integration of channel slope vegetation with manmade materials such as rock riprap, flexible channel liners (turf reinforcement mats), coconut fiber rolls, or other similar materials. Reinforcement approaches vary from loose rock riprap (targeting primarily erosion) to synthetic turf reinforcement mats (targeting primarily vegetation establishment). These techniques can be distinguished from pure soil bioengineering techniques which rely on vegetation alone to maintain slope stability and prevent streambank erosion. The flashy nature of urban streams frequently prohibits the exclusive use of soil and vegetation in restoring unstable stream channels (Kelly, 1997). Figure 3-27 presents a typical approach to vegetative reinforcement.

Applicability

Long-term stability of biotechnical measures along stream courses depends on establishing a dense, self-perpetuating plant community which binds soils together with root systems and provides surface protection against erosive forces by means of exposed shoots, stems and leaves. Vegetation reinforcement techniques provide protection and support to the vegetative cover both during the critical period of initial establishment and during periods of high erosive flows and channel shear stresses. Vegetation reinforcement techniques are applicable in conjunction with establishment of natural channel designs, in high velocity and high shear stress streams, and at locations of severe channel bends in conjunction with appropriate toe protection.

Effectiveness/Advantages

- Vegetative reinforcement techniques provide effective protection for new vegetation and support for established vegetation during periods of high flow.
- This approach can be used effectively in the natural channel design process.
- Application of these approaches can occur on steep slopes.

Constraints

- Hazards exist during initial establishment. Flooding immediately following placement of vegetation reinforcement may result in partial or total loss of the reinforcement product as

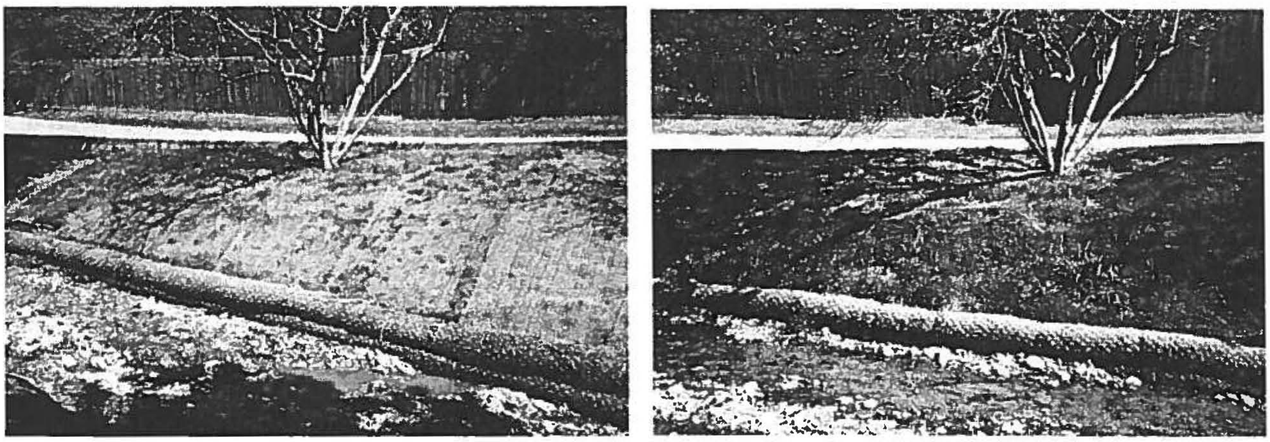


Figure 3-27. Turf reinforcement mat after installation (left) and with established vegetation (right) *Source: City of Austin*

well as plant and soil materials. Proper placement and timing of construction minimizes early vulnerability.

- Presently, only a few contractors have long-term construction experience with this technique which may adversely impact project cost and quality.
- Most vegetation reinforcement measures are not themselves capable of providing erosion protection.

Operations and Maintenance

Relatively frequent inspection and spot maintenance during initial establishment and especially after high flows is necessary for most vegetation reinforcement techniques.

D. Loose Rock Riprap

Description

Rock riprap refers to loose unconsolidated rocks which are placed along eroding side slopes to provide local protection. Riprap may be placed over an extended segment of channel or in isolated trouble spots. Although more labor intensive, riprap provides better protection when hand-placed rather than dumped. High shear stresses encountered in Austin's urban streams usually require rocks 18-inches in diameter or larger. Riprap performs well when used in conjunction with vegetative slope protection techniques which serve to stabilize the underlying soil. In the case of rock riprap, the size of rock used to stabilize the toe of the slope must be such that its weight can resist the shear force exerted by the flowing water at a depth corresponding to the 25-year event (Kelly, 1997). Figure 3-28 presents a loose rock riprap design in conjunction with vegetation revetment.

Applicability

Due to the ability of rock riprap to withstand high shear forces and velocity, this treatment performs well in high energy stream systems. Typical uses include: (1) protection of severe

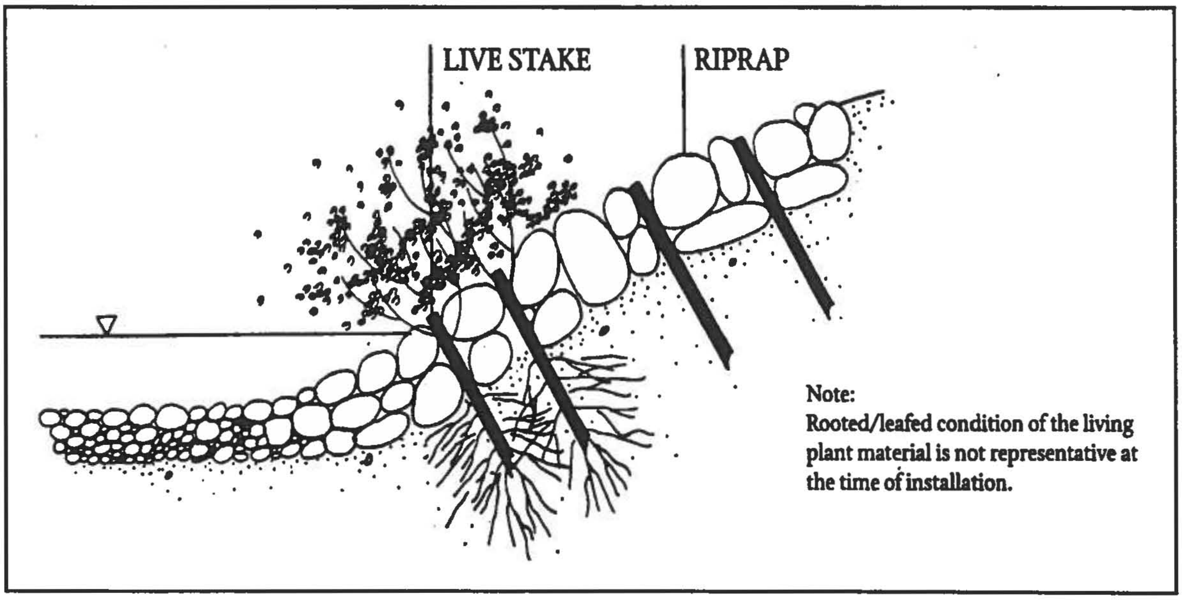


Figure 3-28. Illustration of loose rock riprap *Source: Robbin B. Sotir & Associates*

channel bends; (2) protection of structures and roadways and provision of transitions into and out of box culverts, bridges, and channel improvements (this treatment can minimize scour and reduce velocities as stream flow moves from concrete to the natural channel bed); (3) placement in parklands since loose rock riprap can provide a natural appearance, especially once vegetation grows into the rock void spaces; and, (4) as part of the natural channel design process.

Effectiveness/Advantages

- Loose rock riprap can withstand long durations of high flow, shear stress, and velocity.
- This technology has a natural appearance when vegetation grows into the rock void spaces. A practice called joint planting introduces vegetation into the rock void spaces to accelerate the vegetation coverage.
- Loose rock riprap generally has a much lower cost than gabions and concrete and usually costs less than bioengineering and biorevetment.
- The Austin area contains significant quantities of available rock which helps keep costs down.
- Some habitat is offered by this treatment (but not to the level of biorevetment or bioengineering).
- This approach readily drains groundwater behind the treatment avoiding specialized groundwater drainage systems.

Constraints

- Loose rock riprap should not be placed on steep slopes (greater than 1.5H to 1V) or flatter to maintain slope stability. Therefore, this treatment can not be used in narrow, deep channels.
- The toe of the rock riprap needs to extend several feet below the channel surface to at least the expected scour depth from the 25-year flood or into bedrock.
- Geotextile filter fabric may be required behind the rock if it is necessary to minimize the movement of fines through the rock void spaces.
- This treatment offers less resistance to flow than vegetative treatments, therefore stream velocities can be higher for a given water surface elevation through a loose rock riprap-lined reach.
- Large scale construction activities can cause loss of vegetation due to installation and long slope lengths.
- Loose rock riprap can be undermined if vegetative or other slope treatments are not used to stabilize the underlying soil.

Operations and Maintenance

Improper installation can result in rocks moving out of position exposing the bank to future erosion problems. Relatively little mowing or vegetation control is required; vegetation growth into the rock is often encouraged. Rampant willow growth into the rocks can increase resistance to flow and possibly elevate floodplain levels, thus vegetation inspection and control is necessary. This treatment is relatively vandal proof with minimal potential for graffiti.

E. Big Rock Toe Treatments

Description

"Big Rock" toe treatments offer protection to especially vulnerable portions of a streambank for stabilization. This method is often used in conjunction with other side slope stabilization methods. Local scour typically occurs at the outside of a bend, in the area downstream of a stormwater outlet, at bridge piers, and along wastewater lines. Channel stabilization measures must be fortified in these areas, and big rock toe treatments help ensure that the toe, or foundation, of a slope is not undermined by scour (Kelly, 1997). In addition, in streams of high shear stress and velocity, the rock toe can be extended to the active channel depth to maximize the treatment success. Figure 3-29 presents a typical big rock toe treatment.

Applicability

Big rock toe treatments are used in high velocity channel reaches; they are particularly important at bridge and culvert constrictions and at unnatural stream bends caused by channel modifications. Big rock stabilization supports the base of a channel sideslope for bioengineering, structural biorevetment, and rock riprap treatments. This technology works well in park situations with other treatments since natural aesthetics are not compromised. This approach can be used in conjunction with natural channel design to maintain long-term bank integrity.

Effectiveness/Advantages

- Big rock stabilization can withstand long durations of high velocity and shear stress forces on the bank.
- This approach exhibits a natural appearance when vegetation becomes established.
- Many sources of rock in the Austin area make this approach economical.

Constraints

- This technology is not necessarily a treatment by itself, but generally supports other treatments on the stream bank by minimizing their susceptibility to scour.

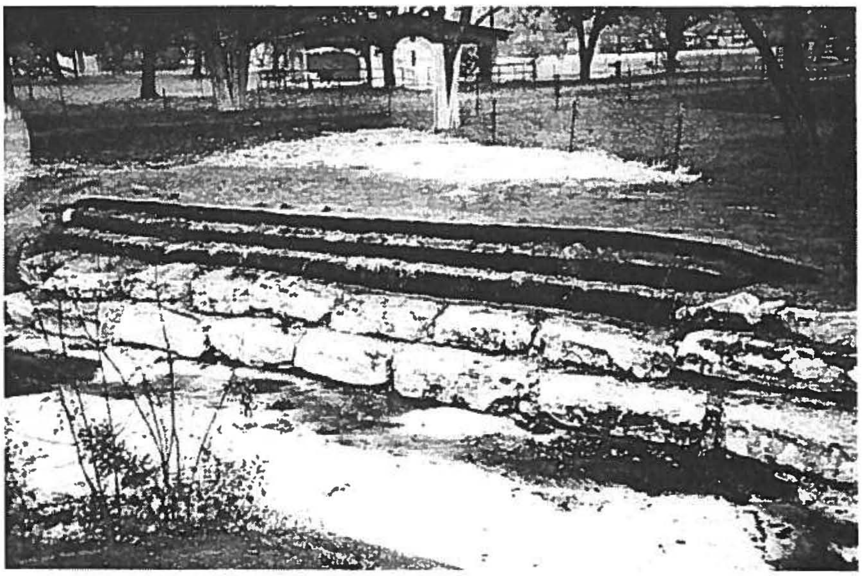


Figure 3-29. Big rock toe treatment at Gillis Park in combination with reinforced earth
Source: City of Austin

- Rock sizes required may be of such magnitude that placement is difficult and special equipment is required to move the rock into the proper location.
- If used to the active channel depth, stream velocities can be increased for frequent storm events.

Operations and Maintenance

If properly installed, maintenance is minimal or nonexistent. This approach is relatively vandal proof with little potential for graffiti.

F. Gabions (Rock and Wire Baskets)

Description

Gabions and wire baskets are coarse wire mesh baskets filled with stone and rock. (The term "gabion" is a trademark name for a specific type of rock and wire basket.) These materials are stacked to form a gravity-type wall. Gabion walls can be used in streams and ponds to change flow patterns, stabilize banks, or prevent erosion. Gabions have been used as retaining walls, channel linings, drop structures, check dams, spillways, and energy dissipaters. Gabion walls can be effective means of erosion control for channels with steep banks. Figure 3-30 illustrates a gabion channel revetment application on relatively steep slopes.

Applicability

Gabions are used in high velocity channel reaches, especially in locations where use of bioengineering could cause increased flood elevations. They are used at bridge and culvert constrictions and at unnatural stream bends caused by channel modifications. Other uses include: (1) narrow, deep channels (confined channel systems) when existing structures or right-of-way constraints limit the ability to slope the bank; (2) due to their structural nature, to protect banks with large structures perched at the bank top; and (3) for construction to extreme heights (40 feet) as in Little Walnut Creek.

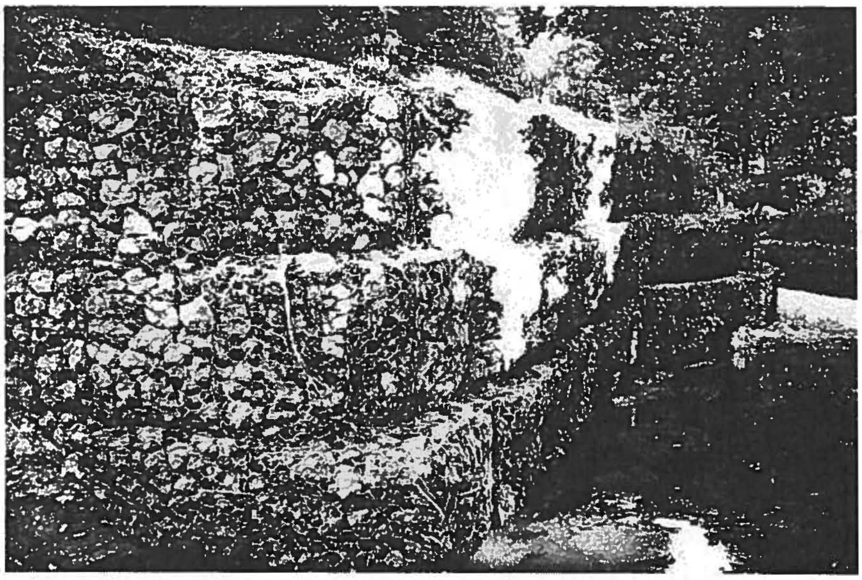


Figure 3-30. Gabions on Shoal Creek at Northwest Park Source: Loomis & Moore

Effectiveness/Advantages

- Gabions are locally effective in reducing channel erosion; however, the localized reduction in erosion could be offset by increases in flow velocity caused by improved channel conveyance.
- Local contractors are experienced in the implementation of gabions resulting usually in competitive prices and quality installations.
- Gabions can withstand long durations of high flow and shear stress forces.
- Due to the rock construction, groundwater can typically migrate through the wall without specialized groundwater drainage systems.
- Gabions are much more flexible than concrete and can withstand some bank and bottom movement without compromising structural stability.
- Gabions have been used on numerous erosion control projects in the Austin area and are a proven performer in stream bank erosion control.

Constraints

- Gabions can result in erosion of the channel bottom or banks at the downstream interface with the natural channel. This can result in a continued need to install additional erosion control measures.
- This technology generally requires an extensive footing into the channel bed, either into bedrock or below the scour depth.
- Gabions require filter fabric behind the wall to minimize loss of soil through the rock. Proper backfill and compaction is required behind the wall for groundwater flow and structural support.
- If a gabion wall is built to considerable height, the base foundation needs to be fairly large in width causing large construction work areas and the potential loss of vegetation.
- Gabions are generally not considered to be an aesthetically positive channel revetment type, often limiting their use to urban streams that lack the necessary right-of-way for vegetative treatments.
- In practice in Austin, gabions installed 10 to 15 years ago have shown extensive corrosion damage and loss of rock. This may have resulted from an inadequate PVC coating, localized erosion, or improper construction techniques.

Operations and Maintenance

Ongoing inspection of gabions is necessary. If rocks are not of sufficient size, they can migrate from the basket causing the basket to slump and fail (as on lower Shoal Creek near the hike and bike trail). Gabions installed 10 to 15 years ago in Shoal Creek near 34th Street show extensive corrosion damage and loss of rock. Vandals can cut the wire causing loss of rock and failure of individual gabion cells. Due to the uneven surface, graffiti potential is low.

G. Concrete Riprap

Description

Concrete riprap consists of concrete slope paving that is used for surface protection in erosion-prone areas. Concrete riprap generally is not designed to provide structural stability and should be placed on channel sideslopes slopes no greater than 1.5H to 1V. Concrete riprap is generally steel-reinforced to limit cracking and structural failure and is usually 4-6 inches thick with a smooth face, a substantial footing, and a grade beam along the top of the channel slope. By nature, concrete is flexible with respect to meeting unusually-shaped revetment needs and completely familiar as a working material for contractors. Figure 3-31 illustrates a typical channel revetment application for concrete riprap.

Applicability

Concrete riprap is a flexible and moderately low cost channel revetment treatment. Riprap is particularly useful in the following situations: (1) sharp bends of banks with a less than 300 feet radius; (2) at locations of high turbulence and flow velocity, such as at a bridge or culvert; (3) along the opposite bank at the confluence of two streams; and (4) on streambanks where high flow rates and velocities occur; (5) around storm drain outlets and drop inlet structures; and, (6) in narrow, deep channels with concrete riprap on the bottom and structural concrete walls (City of Austin, 1992). Concrete riprap in combination with concrete walls has been used for large channel stabilization projects in Austin (e.g., Boggy Creek, Tannehill Branch).

Effectiveness/Advantages

- Concrete riprap is a highly effective erosion protection technology at the application site; (however, localized reductions in erosion can be offset by downstream increases in flow velocity and erosion caused by increased channel conveyance through the riprap area).
- If properly designed, this technology can withstand long durations of high flow and high velocity shear forces.

Constraints

- Increases in downstream erosion are possible resulting in the continuing need to install additional structural erosion control measures.
- Concrete riprap is intended as a permanent solution but its rigid structure is often not compatible with the dynamic stream environment. Many erodable channel banks are difficult to control structurally. Some structural failures are likely which can aggravate adjacent erosion problems in future floods.

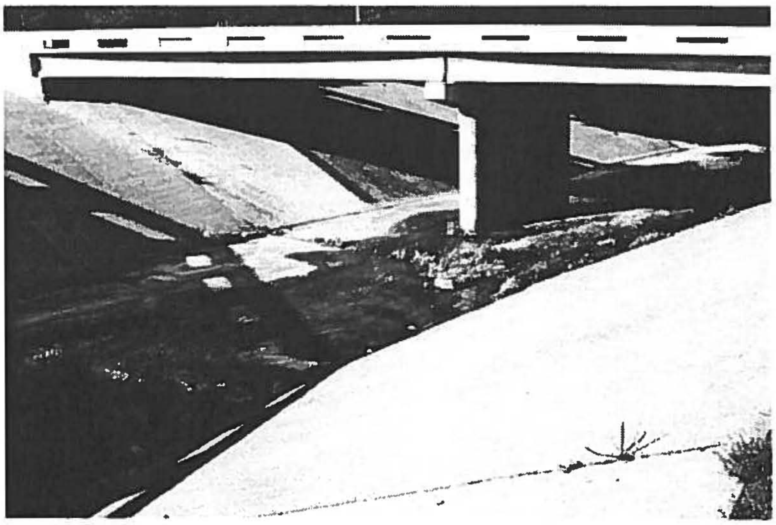


Figure 3-31. Channel lined with concrete riprap *Source: Loomis & Moore*

- Concrete riprap is often considered visually unattractive by comparison with vegetative channel revetment techniques. This technology is generally poorly-suited to application in parks, public recreation areas, and neighborhoods, especially since they are frequently covered with graffiti.
- This erosion control approach offers no habitat benefits or water quality treatment and increases velocity downstream of the project limits.
- Groundwater levels behind the concrete can pose problems and special underdrain systems are necessary to manage groundwater levels.
- Concrete riprap requires extensive footing and natural channel interface protection to prevent scour along and downstream of the concrete-improved channel section.

Operations and Maintenance

Periodic inspections are necessary. Failures generally occur due to undermining and headcut migration. When failures occur, they are often widespread due to the rigidity of the system. Concrete channel slopes and bottoms are frequently subjected to graffiti. Graffiti clean-up is expensive and graffiti re-occurrence likely. If properly installed, with downstream scour protection, structural repair requirements and maintenance are minimal.

H. Mortared Rock

Description

Mortared rock revetment refers to stacked rock cemented with mortar and used, like concrete riprap, for surface protection in erodable streams. The primary advantage of mortared rock is the perception of relatively high aesthetic value in comparison with gabions or concrete riprap. Mortared rock can be utilized as non-structural slope protection, as a facing for non-structural concrete, or as a facing for structural concrete walls. Mortared rock provides moderate channel friction (less than vegetation and more than concrete slope paving). Figure 3-32 presents a failed mortared rock design.

Figure 3-32. Example of a failed mortared rock embankment *Source: City of Austin*

Applicability

This technology is generally used in narrow, confined channel areas where aesthetic treatments are desired and vegetative revetment is impractical. If properly designed and constructed, mortared rock provides effective protection with relatively high velocity streams, but is generally not considered as reliable as concrete riprap, gabions, or reinforced earth. Mortared rock is often used in localized applications where aesthetics are considered important such as with channel drop structures or for facing around headwalls and wingwalls. It has been widely applied in Austin along flood-prone sections of Shoal Creek (over 0.5 miles of channel) where residents desired an aesthetic channel treatment.

Effectiveness/Advantages

- As with all slope paving technologies, if structurally sound, mortared rock is an effective structural erosion protection approach and can withstand long durations of high flow and high shear stress.
- Mortared rock can provide a high degree of aesthetic appeal with minimal threat from graffiti artists.

Constraints

- Although intended as a permanent solution, the rigid structure nature of mortared rock has been shown in practice in Austin to be poorly compatible with the dynamic stream environment. Frequent problems include undercutting at the upstream and downstream interfaces, significant erosion along the toe of the sideslopes, and degradation of the mortared rock face.
- Mortared rock can contribute to downstream erosion due to increased flow velocities through the improved section or localized turbulence at the interface with the natural channel. This can result in a continued need to provide additional structural erosion control measures at interface locations.
- Mortared rock offers no habitat benefits or water quality treatment.
- Groundwater levels behind the mortared rock can pose problems and specialized drainage systems are necessary to manage hydrostatic groundwater pressures.
- Mortared rock requires extensive footings, downstream toe and rock riprap to prevent downstream scour holes and bank erosion.
- If a concrete footing is not established into the channel bottom, failure occurs in a relatively short time period as on Shoal Creek. Rocks can be removed from the wall due to foundation settling and stream flow forces. Once a rock is removed, stream flow has the ability to rapidly facilitate further deterioration.

Operations and Maintenance

Periodic inspections are necessary to detect undermining and headcut migration. When failures occur, they are often widespread due to the rigid structure system. Graffiti occurs but is significantly less frequent with this technology than for concrete riprap.

3.3.3 Natural Channel Design

Description

Natural channel design refers to engineered modifications to urbanized stream channels to achieve long-term stabilization of channel form. These designs generally replicate channel forms found in undisturbed natural stream systems, though considerations are made for the greater flow volumes and velocities found in urbanized streams. Natural channel designs seek to accommodate the channel forming discharge (CFD) which regulates the dimensions of the active channel. In urban streams that are incised (downcut) into the floodplain, this flow may have a mean recurrence interval ranging from three months to one year (Chan & Associates, 1997).

In unimpacted, rural streams, little incision exists and the depth of flow during channel forming discharges is shallow enough that flow spills out onto the floodplain; velocities, depths, and shear stresses are all thereby reduced. In urban streams, the opposite occurs. As the channels attempt to adjust to high urbanized flows, they become deeply incised; CFDs become disconnected from the floodplain and there is no "relief conveyance" into which flows can spill over. Velocities and shear stresses are thus increased and magnified, increasing erosion and bank failure.

Natural channel design offers a means of reconnecting the active channel with a floodplain. When reconstructing the channel geometry of an entrenched stream, the water surface elevation of the CFD is a good benchmark for the height of a floodplain terrace. The sediment-discharge relationship that forms the active channel will more closely retain the aforementioned channel geometry, avoiding excessive erosion or sedimentation. In many cases an additional inset channel will form within the enlarged active channel. This inset channel contains the typical low flow, which has positive impacts on aquatic habitat. The result is a series of "nested channels" formed within the enlarged original channel.

The City of Austin has recently completed watershed erosion assessments that provide planning level estimates of the channel forming discharge, depth, and estimated future channel enlargement due to urbanization. For large channel restoration projects, more detailed geomorphic/hydraulic studies are needed to pinpoint the elevation of the channel forming discharge. In addition, knowledge of the frequency of inundation by the CFD is necessary for the selection of appropriate native plants in the riparian zone (Kelly, 1997).

The following are descriptions of commonly used natural channel design techniques:

Terracing. Terracing promotes re-connection of a deeply cut channel to its floodplain through excavation of a floodplain area adjacent to the impacted channel. The terrace is cut to allow the inset channel to carry the 1- to 2-year storm, and the floodplain provides relief for larger storms. The most significant drawback to terracing is loss of trees or other desirable vegetation. But in many cases, impending channel degradation may already threaten the existing vegetation, and therefore

TERRACING

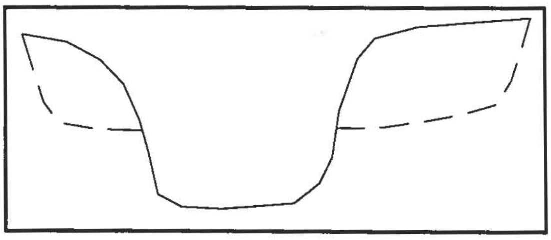


Figure 3-33. Section view of terracing (dashed line) to reconnect a channel (solid line) to its floodplain
Source: Loomis & Moore

terracing would provide a stable platform for re-vegetation for a longer-term solution. Figure 3-33 presents a typical terracing application.

SIDE CHANNEL

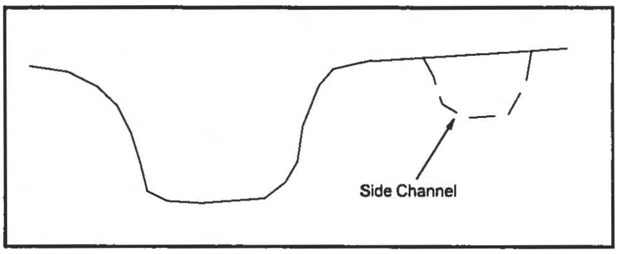


Figure 3-34. Section view of side channel
Source: Loomis & Moore

Side Channels. Side channel construction reduces water surface elevations and flow velocities by providing a parallel flow route to the main channel. The side channel, which typically remains dry during low flows, is established with native vegetation, and provides additional conveyance as well as storage during storm flows. As with terracing, side channel construction may eliminate existing riparian vegetation. Figure 3-34 presents a typical side channel configuration.

RE-MEANDER

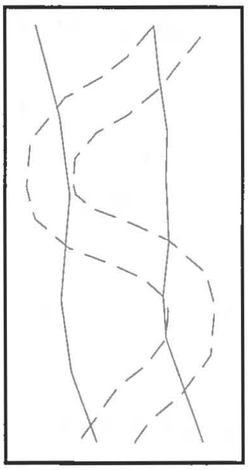


Figure 3-35. Re-meander (dashed line) of a straight section (solid line)
Source: Loomis & Moore

Re-meandering. Re-meandering refers to restoration of the natural meandering channel flow path to increase stream length and reduce channel slope. This technology is typically employed as a restoration measure for streams that have been straightened and armored. The resulting flow has lower stream energy and therefore lower erosion potential. Typically, the restored channel provides less conveyance than the "improved" channel with increased floodplain conveyance compensating for the reduction in channel conveyance. Figure 3-35 shows a re-meandering configuration.

Raising the Channel Bed. A highly-entrenched channel contains a broad range of low flow and higher flow events. Before the channel became entrenched, the floodplain provided relief for the larger floods. Raising the channel bed returns high flow events to the floodplain and reduces channel shear stress. Drawbacks include temporary loss of habitat and higher flow depths. If the floodplain cannot carry extreme events due to new hydrologic conditions, then raising the channel bed will create new flooding problems. Figure 3-36 shows a typical bed-raising cross section.

Artificial Shoals. When watershed conditions create a channel degradation problem, the channel tends to downcut until it encounters a non-erodable material. Where the limiting substrate is deep below the original natural creek bed, it may be advisable to arrest further downcutting

RAISING THE CHANNEL BED

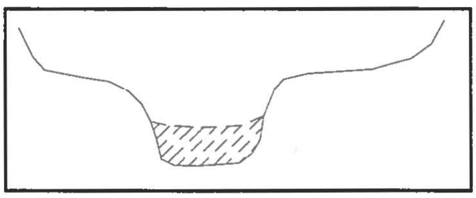


Figure 3-36. Section view of raising the channel bed (hatching) to reconnect a channel (solid line) to its floodplain
Source: Loomis & Moore

ARTIFICIAL SHOALS

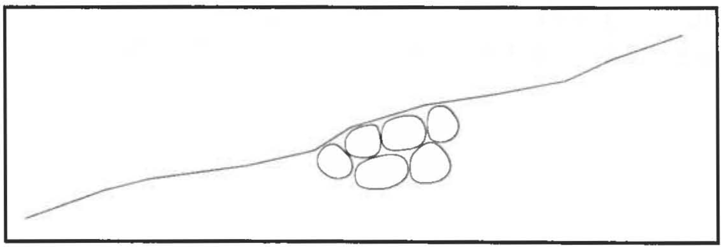


Figure 3-37. Large rocks buried beneath the channel flowline to form an artificial shoal
Source: Loomis & Moore

through creation of artificial shoals. A common application of this approach utilizes large rocks (18 inch or greater diameter) buried beneath the channel flowline to form a barrier to downcutting. Caution must be taken to ensure that a downstream headcut does not migrate to the structure, which can create a scour pool and widen the channel. Figure 3-37 presents a typical artificial shoals design.

Applicability

Natural channel design approaches are generally applicable only in areas where riparian land availability is high. Confined, deeply-cut, urban channels offer minimal opportunity for increasing floodplain conveyance to reduce channel flow velocities. Width/depth adjustments, terracing, re-meandering, construction of side channels, and measures for reducing main channel flows while increasing floodplain flow all require the ability to widen the flow path.

Natural channel design technologies frequently require removal of existing riparian vegetation. In areas where large, valuable trees must be removed to accommodate channel re-contouring, the existing value of the riparian vegetation must be weighted against the long-term erosion threat (including to the riparian vegetation itself).

Effectiveness/Advantages

- Natural channel design approaches can provide long-term channel stability with high aesthetic appeal.
- These technologies generally require low maintenance since they are specifically designed by reduce erosion and discourage stream aggradation and degradation.

Constraints

- In urban areas, limitations in the width of the riparian corridor often preclude the use of these techniques.
- Natural channel design measures can potentially yield large-scale bank disruption, destruction of habitat, and loss of established riparian vegetation.
- Construction activities associated with creation of riffles, pools, shoals, and raising of the channel bed generally create significant, localized, in-stream disturbances, substantial construction-phase sediment loadings, and temporary loss of habitat.

Operations and Maintenance

Operation and maintenance varies among the methods described above. For the most part, well-constructed, natural channel modifications require little maintenance. Vegetation management and selective control of non-desirable species may be required in the short-term to promote the growth and survival of appropriate species. Long-term programs for trimming vegetation may be necessary to limit negative flood conveyance impacts.

3.3.4 Stormwater Detention for Erosion Control

Description

For urbanized watersheds with high channel enlargement ratios, stormwater detention offers a means of regulating peak flow rates to promote channel stability. Stormwater detention measures which target erosion control are generally designed to mimic the predevelopment frequency of channel-forming runoff events (although runoff flow durations may be increased) by temporarily storing the storm runoff volume and regulating discharge flow rates. Determination of appropriate outlet structure sizing and design release rates should consider downstream shear stress thresholds beyond which channel instability can occur.

Applicability

Stormwater runoff detention is applicable and effective for prevention of future erosion problems. It is not generally useful for remediation or repair of current active erosion sites, except as a means of slowing erosive flow pressures. Runoff detention for erosion control generally requires capture and control of the 6-month to 2-year runoff volume depending upon downstream channel conditions (i.e. rock-controlled vs. alluvial). Consequently, substantial land area for online or offline runoff storage is necessary for this approach. Erosion control volume can be provided in conjunction with other components of a multi-mission water quality (wet pond), baseflow, or flood control facility. If sufficient space is available, erosion storage can be provided as a retrofit to existing flood control or water quality ponds.

Effectiveness/Advantages

- If properly designed, constructed, and maintained, erosion storage facilities provide effective, reliable and predictable performance.
- Detention ponds can be potentially combined for additional, beneficial public uses. As a component in a multi-mission BMP, erosion storage facilities can be designed for park or recreational use as well as erosion control.
- Generally good public acceptance. When attractively incorporated into the landscape, vegetated detention facilities can be well-accepted by the public.
- As a stand-alone BMP, erosion storage does not require a permanent wet pool; consequently on-line erosion storage will not necessarily threaten riparian habitat or vegetation.

Constraints

- Stormwater detention facilities require relatively large areas for storage of the design event. Thus, erosion control design or retrofitting can be difficult in urbanized areas where the need for runoff storage is greatest and open land space minimal.
- Placement of erosion storage in the lower portions of a watershed can exacerbate flooding by delaying the lower basin peak flow to coincide with the whole basin peak.
- If erosion volume detention disrupts the normal movement of sediment through the stream system, changes in sediment concentration may interfere with stream equilibrium and exacerbate erosion processes downstream. An off-line detention storage configuration can be effective while preventing disruption of bed load movement.
- Widespread application of 6-month to 2-year runoff storage can result in negative flood impacts through accumulation of recession limb flows. Recognition and avoidance of this effect is possible through basinwide planning and hydrologic modeling.

Operations and Maintenance

Grass-lined facilities require regular mowing, and structures with small outlets or standpipe outlets may require trash or debris removal. Sediment must be periodically removed to ensure the facility retains its original design volume. Inspection of inflow and outflow structures is necessary to assure continued structural integrity.

3.3.5 Other Flow Attenuation Practices

Description

Although long-term channel enlargement is best prevented through control of peak flows from small events (6-month to 2-year), additional marginal reductions in bank erosion and sediment loads can be achieved through application of water quality management practices that reduce runoff and promote infiltration. These include:

- Impervious Cover Removal
- Impervious Cover Disconnection
- Rainwater harvesting
- Porous pavement
- Bioretention
- Retention-Irrigation Ponds
- Infiltration basins and trenches
- Vegetated filter strips
- Grassed Swales

If sufficient land area and appropriate topography is available, several water quality control practices can be retrofit to provide erosion control through reduction of smaller event peak flow rates. These include:

- Sedimentation/sand filtration ponds
- Extended detention ponds
- Wet ponds
- Stormwater wetlands

Discussion

All of the above methods target primarily water quality control, although all are effective in reducing erosion in urban creeks. They differ from direct erosion site and flow control detention practices in that they are effective only if required and applied on a widespread, institutional (regulatory or programs) basis. Each practice individually provides only marginal peak flow and erosion control; however, as part of a watershed-wide water quality strategy, the collective effect could be substantial collateral erosion control through mimicking pre-development watershed conditions (decreased runoff and increased infiltration). In-depth discussions of the above practices are presented in the Water Quality section of this inventory.

A. Check Dams

Description

Check dams are small, low head dams installed at multiple locations along drainage channels and urban creeks. For small flows, check dams provide increased cross-sectional flow area, reduced velocities, and promotion of solids deposition. For higher erosive flows (6-month to 2-year) they provide increased channel friction, increased flow depth, and reduced flow velocities. In general, they function to reduce the energy and erosive capacity of runoff flows. Debris

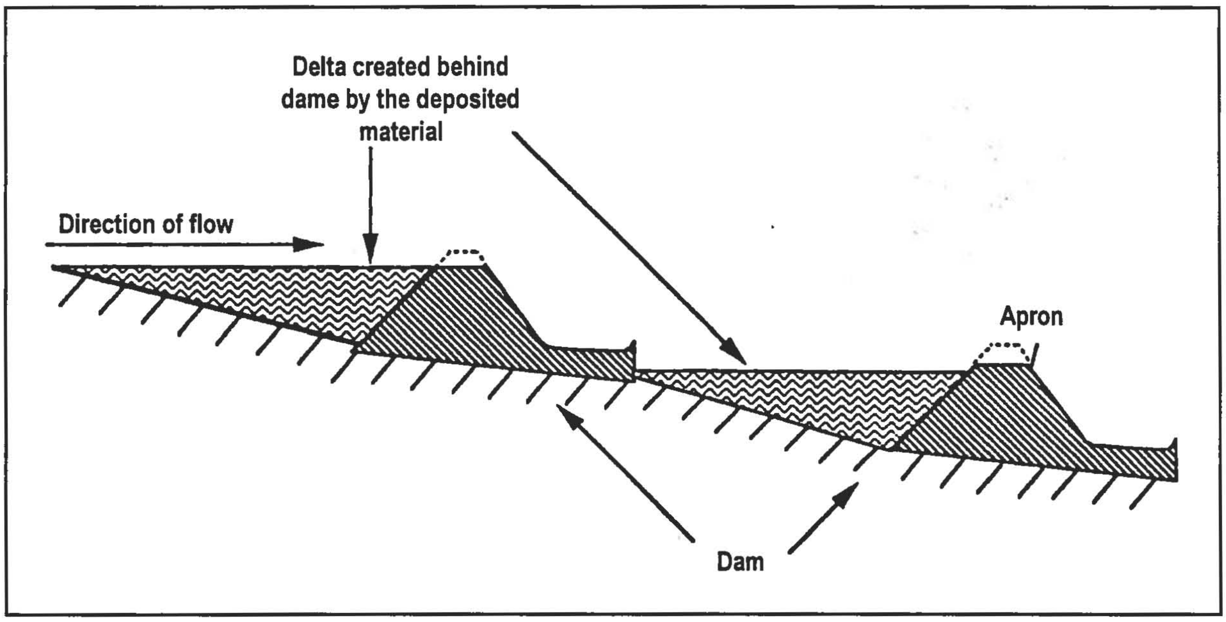


Figure 3-38. Cross-sectional view of a gully check dam *Source: Gray and Leiser, 1989*

and sediment trapped in the check dam pool can provide grade stabilization. Figure 3-38 presents a schematic design for a gully check dam.

Applicability

Check dams can be used where other structural and/or vegetative measures would not be effective in controlling velocities, especially where excessive grade differences occur. Check dams can be used as a substitute for channel lining in earth channels or as protection for grass or vegetation-lined channels during initial establishment. Generally, numerous low check dams function more effectively than fewer high dams. Low dams are less expensive and provide smaller flood impacts and dam safety problems.

Effectiveness/Advantages

- Check dams are effective and reliable for prevention of gully erosion and for capture of sediment. The efficiency of sediment control by a check dam may be as high as 75% for low intensity storms (COA, 1992).
- Check dams can provide marginal control of nutrients (through low flows storage and biodegradation), control of pesticides and other toxics (through sediment deposition and capture), and enhanced reaeration of streams (by promoting spillover and turbulence).

Constraints

- In constrained, flood-prone areas, the use of check dams may be inadvisable due to increased channel friction and potentially increased flood threat.
- High flow around the edges of the dam can cause erosion and threaten structural integrity. Thus, check dams should be regularly inspected and maintained.
- The benefits of check dams can be lost during large storms. If maintenance is inadequate (accumulated sediments removal), high intensity storms may wash out all or portions of the trapped material. For this reason, check dams may not be appropriate as erosion control measures for large creeks with high peak flows.

Operations and Maintenance

Check dams must be periodically inspected and maintained to prevent erosion, threats to structural stability, and excessive sediment accumulation.

3.3.6 Measures for Localized Erosion Problems

A. Outlet Protection at Storm Drain Outfalls

Description/Applicability

Outflow from storm sewers and culverts often creates localized scour due to a concentration of flow and high velocities. Excessive flow velocities occur when outfall pipes are steep or pipe flow is pressurized. The following list describes measures for reducing outlet scour:

Baffles. Baffles consist of an array of concrete blocks which slow outlet flows by creating turbulence and/or forcing a hydraulic jump (subcritical flow with higher depths and lower velocities).

Flattening the Outfall Pipe Slope. Flow accelerates in steep pipes to supercritical velocities and low flow depths. Replacing the end section with a flat section of pipe slows the flow and forces a hydraulic jump within the pipe. Slowing the velocity before the flow leaves the pipe prevents additional scour associated with the turbulence in a hydraulic jump.

Roughening the Outlet Section. Forming slats or small baffles within the outfall pipe creates roughness within the pipe that provides the same effect as reducing the pipe slope. It slows the velocity and forces a hydraulic jump within the pipe.

Extended Concrete Apron. An extended section of concrete at the outfall provides protection to the stream bed where the outfall flow transitions to stream flow. This method of protection is itself vulnerable to undermining at the sides and edge of the apron by both the outlet flow and the stream flow. This method should use rock riprap of sufficient size around the edges to prevent undermining and create a roughened surface to minimize channel erosion.

Effectiveness/Advantages

- Outlet protection prevents localized erosion and potential upstream migration of headcuts or downstream erosion from scour hole turbulence.

Constraints

- Outlet protection has the potential to cause erosion problems. Baffles, projecting pipes, or concrete aprons may introduce new erosion problems or vulnerability to undermining when they are not correctly installed.

Operations and Maintenance

Typically, outlet flow structures experience scour development downstream of the apron and eventual damage to the concrete structure. Inspection of aprons and headwalls should be performed on a periodic basis and rock riprap used to minimize existing scour hole problems.

B. Flow Deflectors

Description

Flow deflectors provide bank protection by promoting deposition and retarding channel movement. Flow deflectors are constructed by placing boulders, gabions, railroad ties or other objects along a channel segment. Deposition that forms behind the deflectors can generate growth of vegetation and promote additional stability. Location of channel deflectors on the outside of a channel bend is generally intended to force the thalweg (deepest portion of the channel) to move away from the bank toe and toward the middle of the channel thereby reducing the presence of erosive velocities on the outside bank. Figure 3-39 shows a schematic of flow deflector placement along a stream meander.

Flow Deflectors

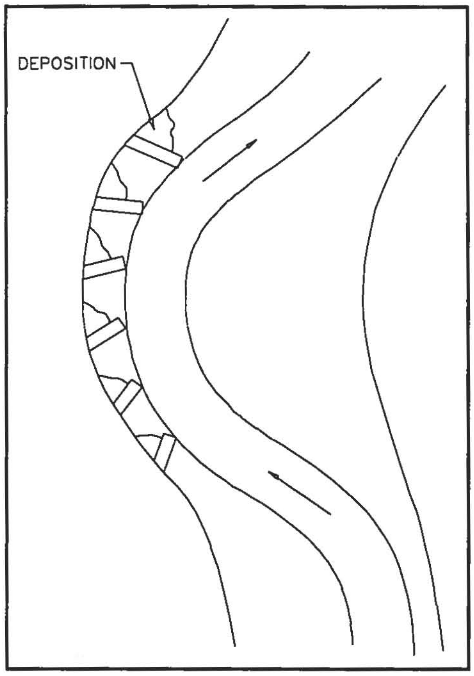


Figure 3-39. Flow deflectors
Source: Loomis & Moore

Applicability

Flow deflectors are generally most applicable on severe channel bends where high flow velocities are undercutting the bank and promoting bank erosion and vegetation loss. This technology can be used in combination with reinforced earth, bioengineering, gabions, loose rock riprap structures, and concrete riprap.

Effectiveness/Advantages

- If properly designed and constructed, flow deflectors can be effective and reliable for prevention of erosion of the outside bank.
- This technology is passive and simple.

Constraints

- Unless carefully designed (preferably with the assistance of a physical model), flow deflectors may result in unexpected hydraulic and erosion consequences (downstream scour holes or bank erosion). Ongoing and unpredictable stream instability is likely.
- Flow deflectors must be sturdy to remain in place after direct hits by flood flow debris.
- Altered erosion and deposition patterns and new vegetative growth patterns will generally require periodic inspection and channel maintenance.

Operations and Maintenance

Inspections and maintenance should occur periodically to address altered erosion and deposition patterns and new vegetative growth. Inspections should especially occur after large flood events to verify performance, structural integrity, and to identify new erosion patterns or problems.

4.0 Initial Solutions Selection Protocols Development and Implementation

Solution selection protocols were developed to define procedures for preliminary selection of capital, programmatic, and regulatory solutions. These protocols provide a systematic procedure for initial screening and solutions selection from among the complete range of solution types defined in the inventory.

Factors considered in the initial selection of regulatory and operating program solutions and/or CIP projects include:

- Reach and site-specific problems information provided by the Watershed Protection Department regarding solutions applicability and effectiveness;
- City of Austin topographic and planimetric maps with designation of open spaces to identify potential locations for site-specific stormwater management practices;
- Previous local studies and technical literature identifying optimal stormwater management technologies and sites;
- Information on the type and location of Watershed Protection Department capital projects to be implemented in the future;
- City of Austin staff experience and philosophy regarding preferred stormwater management technologies.

3 maybe mention

City input to the initial selections protocol was solicited with respect to preferred CIP, regulatory, and water quality stormwater management approaches. This information was used to assist in development of the initial solutions selection protocols and project selection. However, final protocols application and solutions selection was based upon the consultant's independent engineering judgment.

4.1 General Philosophy for Selection of Solutions

Procedures for initial selection of stormwater management solutions are presented in this section. For each combination of mission (flood control, erosion control, and water quality) and solution type (CIP, regulatory, and operating programs), individual solution selection protocols were developed. These are presented in Sections 4.2.1 through 4.2.3 below.

The solution selection protocols were derived based upon fundamental guiding principals that reflect the City of Austin's goals and philosophies for proper stormwater management. These include:

- Integration and Cooperation
- Public Input and Use of Water Resource Infrastructure
- Environmental Integrity, Sustainability, and Low Maintenance
- Optimal Form <u>and</u> Function
- Fairness
- Prevention over Remediation
- Common Sense and Flexibility

Integration and Cooperation – The overriding goal of solutions selection is to maximize benefits for a given expenditure of resources. This is best achieved through maximal integration of solutions and cooperative interaction among City departments. Both of these goals are served by providing a general balancing of solutions recommendations across stormwater management missions; and by acknowledging and exploiting the synergistic benefits of coordinated implementation of capital projects, regulations, and operating programs. Consequently, solutions selection procedures have been configured to promote: (1) solutions integration by mission (flood, erosion, water quality) and type (CIP, regulatory, and programmatic); and, (2) to maximize coordination and communication among City staff.

Public Input and Use of Water Resource Infrastructure – The City of Austin feels strongly that its watershed and stormwater management planning initiatives are provided to serve the public. Extensive public opinion polling and public meetings have been conducted by the City to define watershed-specific levels of concern regarding flood, erosion, and water quality problems. Solutions selection procedures were configured to promote an infrastructure providing maximum public benefit and use of the City's water resources and to reflect public priorities regarding flood, erosion, and water quality problems. Watershed Protection Department goals stress the integration of public recreational uses in stormwater management facilities and along riparian corridors. Multi-purpose facilities, such as Northwest Regional Park, can provide integrated flood control, water quality control, and public recreational opportunities.

Environmental Integrity – The City recognizes the extraordinary public, aesthetic, and economic value of its environmental resources. Solutions selection procedures were therefore configured to emphasize the use of natural solutions and bioengineering; and to promote nonstructural solutions in favor of environmentally intrusive, hard ~~solut~~ions. For example, a reinforced earth channel bank with vegetative facing is generally preferred ~~as an~~ erosion solution over concrete channel revetment. Protection of val~~uable trees~~ and riparian habitat is considered a high priority. Permanent preservation of open spaces through land or conservation easement acquisition is considered a strongly viable strategy for Austin.

Sustainability and Low Maintenance – Although critical for the long-term effectiveness of structural practices, maintenance requirements potentially represent an extraordinary financial burden to the Watershed Protection Department. Sustainable, passive, low maintenance measures are therefore preferred to solutions with expensive operations and maintenance needs. Where high maintenance requirements conflict with the preference for aesthetic, high performance technologies (i.e., wet ponds), solutions selection is based upon a weighing of maintenance costs vs. performance. In general, simple, sustainable and self-perpetuating technologies are preferred over structural technologies. Where structural approaches are necessary, those with enduring strength and reliability are favored. Large-scale or regional structural solutions are preferred over multiple, small-scale applications due, in part, to the lower maintenance burdens.

Optimal Form and Function – Although proper function is critical, a solution's aesthetic appeal is important. The character and image of the City and its neighborhoods can be negatively impacted by large concrete structures, large scale gabion channel treatments, or trapezoidal channel configurations with structural revetment. The selection protocols for CIP projects provide higher benefit scores for aesthetically appealing technologies and applications.

Fairness – The City of Austin requires fair and uniform application of stormwater management solutions. Although geographic differences demand differing solution technologies and approaches, Austin's commitment to providing equitable flood, water quality, and erosion management across the City is clear. Solution selection protocols are applied uniformly regardless of watershed or neighborhood. Property or structure buyout policies (amount paid, when offered, perquisites offered) are applied uniformly and equitably.

Prevention vs. Remediation – The City recognizes the economic and aesthetic advantages of preventing stormwater problems rather than remediating them after they have been created. As an extreme example, proper initial floodplain analyses by FEMA engineers would have prevented the City of Austin's existing $60-$100 million Onion Creek flood problem. Regulatory solutions targeting proper design, enhanced City review, and proper construction techniques are likely to save substantial remediative expenditures. Programmatic solutions targeting public education and infrastructure maintenance may provide substantial benefit through avoidance of future problems.

Common Sense and Flexibility – Common sense dictates that the City seek to achieve the greatest amount of stormwater management benefit for the available funding and that the most severe problems in the City be addressed first. The Watershed Protection Department's problems assessment matrices define and rank the most severe problem locations. The solution selection protocols provide a systematic means for deriving benefit and benefit/cost values for each prospective CIP project, regulation, and operating program. Despite this, the project team will not be constrained to select and recommend only the projects rated highest by the solutions selection protocols. The project team will make final recommendations considering both the results of the protocols implementation and an assessment of unquantifiable benefits and subjective considerations.

4.2 SOLUTIONS SELECTION PROTOCOLS FOR CAPITAL IMPROVEMENT PROJECTS

The initial solutions selection protocols for CIP solutions were used to identify individual CIP projects appropriate for subsequent investigation in the feasibility level screening matrix. This process involved two primary elements: (1) selection of generic technologies appropriate for the management of identified watershed problems; and (2) identification of specific capital projects targeting identified problems in the 17 Phase I watersheds.

More than 50 flood, water quality, and erosion management technologies were evaluated in the solutions inventory. To assist with identification of the most practical and effective approaches, Loomis & Moore met with City staff from each of the project missions. Based upon discussions and input from the City and the consultant team, each technology was rated and an overall ~~prioritization~~ developed for each mission.

4.2.1 Water Quality Structural Capital Solutions Identification Protocol

Solutions identification for pond water quality CIP projects was performed using the following systematic protocol:

1. Technology Screening – All 30 water quality capital approaches presented in the Solutions Inventory were considered as potential capital solutions for the Master Plan. Only those approaches deemed suitable for individual evaluation on a broad planning scale were selected. This included technologies applicable at single locations and at relatively large scales with significant, one-time capital costs, such as regional wet ponds, regional extended detention facilities, and land acquisition. Those not considered as specific capital projects were either not judged to be recommendable or were approaches which feature the use of smaller-scale, multiple-site practices, such as bioretention, rainwater harvesting, and inlet filters. While structural in nature, smaller-scale BMPs were considered better suited for application and evaluation as operating programs. The five (5) structural and three (3) nonstructural approaches selected are as follows:

Structural	Nonstructural
1. Wet Ponds	1. Land Acquisition
2. Extended Detention Ponds	2. Conservation Easements
3. Constructed Stormwater Wetlands	3. Riparian Buffers
4. Retention-Irrigation	
5. Grassed Swales	

Swale vs Treatment

Table 4-1 presents the menu of available water quality control technologies with descriptions of why each was or was not considered for CIP application in the present analysis. Land acquisition, conservation easements, and riparian buffers require an evaluation process different from that used for pond BMPs; these approaches are also similar to land acquisition approaches for flood and erosion control. Therefore, land acquisition, conservation easements, and riparian buffers are treated under a separate solutions selection protocol described in Section 4.2.4 which combines water quality, flood, and erosion missions for these approaches.

Table 4-1: Water Quality Capital Solutions: Explanation of Selection, Referral to Programs, or Removal from Consideration

Potential BMPs	Comments	Water Quality Concerns: Effectiveness Grades by BMP* Sediment	Nutrient	Toxics	Baseflow	Phys. Integ.	Trash	Bacterial	Spills
Source Controls									
1. Inlet Filters	Considered as part of a Program	D		D			B		
2. Trash and Debris Booms	Considered as part of a Program						B		C
3. Retrofit Existing Ponds for Trash Removal	Considered as part of a Program						B		
4. Impervious Cover Removal	Considered as part of a Program	B	B	B	A	B		B	
5. Impervious Cover Disconnection	Considered as part of a Program	B	B	B	B	B		B	
6. Bioretention	Considered as part of a Program	A	B	B	B	B	B	B	
7. Infiltration Basins	Not recommended due to clogging	D	D	D	B	D	D	D	
8. Infiltration Trenches	Not recommended due to clogging	D	D	D	D	D	D	D	
9. Porous Pavement	Considered as part of a Program	C	C	C	B	C		B	
10. Rainwater Harvesting	Considered as part of a Program	B	B	B	C	B	B	C	
11. Check Dams	Considered as part of a Program				B	B			
12. Hazardous Materials Traps	Considered as part of a Program	D		A			D		A
Stormwater Treatment Measures									
13. Retention-Irrigation	CIP EVALUATION	A	A	A	B	A	B	B	
14. Wet Ponds	CIP EVALUATION	A	B	B		B	B	B	
15. Constructed Stormwater Wetlands	CIP EVALUATION	A	B	B		B	B	B	
16. Sedimentation/Sand Filtration	CIP EVALUATION	C	C	A		B	B	B	
17. Extended Detention for Erosion Capture	CIP EVALUATION	A	D	D		B	B	C	
18. Extended Detention for Baseflow Enhancement	CIP EVALUATION	B	D	C	A	A	B	C	
19. Grassed Swales	CIP EVALUATION	B	B	B	B	B	B	B	
20. Vegetated Filter Strips	Considered as part of a Program	B	B	B	B	B	B	B	
21. Oil/Grit Separators and Water Quality Inlets	Considered as part of a Program	B	D	C			C	D	C
22. Multi-Chambered Treatment Trains (MCTT)	Considered as part of a Program	B	C	A			B	C	C
23. Inlet Adsorbents	Considered as part of a Program	B	D	D			D		D
Property Acquisition or Enhancement for Water Quality Control									
24. Land Acquisition	CIP EVALUATION	A	A	A	A	A	A	A	D
25. Conservation Easements	CIP EVALUATION	A	A	A	A	A	A	A	D
26. Riparian Buffers	CIP EVALUATION	C	C	C	B	A	C	C	
27. Urban Forestry	Considered as part of a Program	C	C	C	B	A	C	C	
Rangeland Management Strategies									
28. Native Grassland Establishment	Considered as part of a Program	A	A		A	A		A	
29. Control of Livestock in Riparian Areas	Not considered; potential for future use.	B	B			A		A	
30. Use of Specialized Grazing Systems	Not considered; potential for future use.	Effectiveness debated by experts							

* Key to Effectiveness Grades: A=Excellent Benefit; B=Good Benefit; C=Some Benefit; D=Marginal Benefit; Blank=No Benefit

2. Site Identification - In each watershed, all prospective adequately-sized CIP water quality stormwater management facility sites were identified using the City's GIS-based 10-foot topographic maps with designated open space overlays. Over 250 locations in the 17 watersheds were identified). In addition, all existing large-scale regional flood control facilities from the Regional Stormwater Management Program (RSMP) were considered for wet pool retrofit.

3. Field Verification of Sites - Field reconnaissance was performed at each of the more than 250 prospective CIP and RSMP sites to assess: (1) the general site size and layout; (2) critical or constraining environmental features; (3) topographic constraints or opportunities; (4) existing features; and, (5) opportunities for BMP integration with existing features. Field notes were taken at each site ranking these factors and providing an overall CIP site ranking. Approximately 110 sites were removed from consideration following the field reconnaissance. The remaining sites were considered adequate for siting water quality facilities and for subsequent evaluation in the feasibility level screening matrix.

NQ

4. Initial Technology Configurations – The five (5) pond technology components are considered to target water quality/problem elements as follows:

- *Erosion Detention* - Control of erosive flows with the capture and modulated release of 6-month to 2-year storm event flows depending upon downstream channel conditions;
- *Baseflow Detention* – Baseflow augmentation using extremely extended detention volume (approximately 1.5 foot vertical range) released slowly over approximately 21 days;
- *Permanent Wet Pool* - Nutrients, toxics, and sediment control using wet permanent storage;
- *Constructed Stormwater Wetlands* – Nutrients, toxics and sediment control in areas with substantial available land and little topographic relief; and
- *Retention-Irrigation* – High level nutrients and toxics control; expensive and maintenance intensive; this technology was considered only in the Barton and Bull watersheds and in the portion of the Williamson Creek watershed in and above the recharge zone.

explain why WQ

At each prospective CIP site, the following six (6) combinations of water quality technologies were identified for consideration:

1. Permanent wet pool, erosion detention, and baseflow detention;
2. Permanent wet pool with baseflow detention;
3. Permanent wet pool with erosion detention; and
4. Erosion detention only; for sed/contaminant control
5. Permanent wet pool only (wet ponds and, in specific cases, constructed wetlands);
6. Retention-irrigation.

where did channelization go?

2. Site Identification - In each watershed, all prospective adequately-sized CIP water quality stormwater management facility sites were identified using the City's GIS-based 10-foot topographic maps with designated open space overlays. Over 250 locations in the 17 watersheds were identified). In addition, all existing large-scale regional flood control facilities from the Regional Stormwater Management Program (RSMP) were considered for wet pool retrofit.

3. Field Verification of Sites - Field reconnaissance was performed at each of the more than 250 prospective CIP and RSMP sites to assess: (1) the general site size and layout; (2) critical or constraining environmental features; (3) topographic constraints or opportunities; (4) existing features; and, (5) opportunities for BMP integration with existing features. Field notes were taken at each site ranking these factors and providing an overall CIP site ranking. Approximately 110 sites were removed from consideration following the field reconnaissance. The remaining sites were considered adequate for siting water quality facilities and for subsequent evaluation in the feasibility level screening matrix.

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explain why WQ

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1. Permanent wet pool, erosion detention, and baseflow detention;
2. Permanent wet pool with baseflow detention;
3. Permanent wet pool with erosion detention; and
4. Erosion detention only; for sed/[illegible] control
5. Permanent wet pool only (wet ponds and, in specific cases, constructed wetlands);
6. Retention-irrigation.

Where did channelization go?

Spills control and trash and debris management were judged to be inefficiently managed with CIP projects. Areas requiring solutions to these problems were referred for consideration as operating programs.

5. Screening of Technology Configurations - Using field reconnaissance data and watershed maps, each of the six technology combinations were evaluated for feasibility of implementation at each site. Depending upon site constraints identified in the field, some of the technologies were removed from consideration at some sites (e.g., no land available for irrigation, or insufficient drainage area to provide baseflow storage).

6. Calculation of Optimal Facility Size - Required facility sizing estimates were performed individually for erosion capture volume and for permanent water quality volume. For sites treating downstream erosion problems, the target erosion capture volume (6-month, 1-year, or 2-year) was derived as a function of the erosive potential of the downstream channel (alluvial, rock-controlled, rock-bottom, or structurally-controlled). For sites treating water quality, the target permanent water quality volume was derived to provide a VB/VR ratio of 3.1 (See Section 3.0, "Wet Ponds"). The required baseflow storage was assumed to be 1.5 feet of vertical depth over the area of the permanent water quality volume.

7. Calculation of Available Facility Size - Available facility sizing estimates were performed using topographic maps and information gathered from the field reconnaissance. Where the target erosion control, water quality, and baseflow volumes could be achieved, the facilities were sized to provide the required capture volumes. If the required storage volume was not available, the available storage volumes were adjusted downward proportionately. Thus, if a pond had proportions in the optimal sizing configuration of 40% wet volume and 60% erosion volume, these values would be retained in distributing storage volume. In some cases, ponds with multiple technologies had to be sized downward whereas single technology configurations (i.e., wet pool only) could be accommodated at their original, optimal size.

8. Specification of Site and Technology Parameters - For each technology combination and each site selected for consideration in the water quality feasibility matrix, the following parameter information was estimated and recorded in a feasibility matrix input file:

1. Location Description
2. Watershed
3. EII Reach ID
4. Channel Classification (main branch or tributary)
5. Location in Reach (pct. of reach below BMP)
6. Position (online or offline)
7. Impervious Cover (Estimated)
8. Drainage Area to BMP
9. BMP Type (technology)
10. Required Capture for Erosion Mitigation (6-month, 1-year, or 2-year)
11. Irrigation Pond Volume
12. Erosion Capture Volume
13. Wet Pool Volume
14. Baseflow Storage Volume
15. Baseflow Yield (cfs)
16. Pct. of Total Volume Requiring Excavation
17. Water Depth at Dam
18. Dam Length
19. Site Area (footprint)
20. Land Cost

Table 4-2 presents a summary by watershed of the total number of capital water quality pond projects evaluated with the Protocol and the final number and type of projects chosen for evaluation with the Feasibility Matrix. Appendix A-2 presents a tabulation of all sites and site parameters considered for analysis in the Feasibility Matrix.

4.2.2 Flood Control Capital Solutions Identification Protocol

For flood management in creeks, the number of available capital/structural solution types is more limited than for water quality. Consequently, all of the primary available structure management technologies were considered at each problem site. The following is a list of the approaches in relative order of preference:

1. Land and Structure Acquisition;
2. Stormwater Detention;
3. Channel Conveyance Modification;
4. Storm Sewer Modifications;*
5. Bridge and Culvert Modifications;
6. Flood Walls and/or Levees;
7. Flow Diversion Channels or Tunnels; and
8. Structure raising.

* Note: storm sewer solutions were evaluated using a separate Flood Protocol.

<u>**Protocol for Creek Flood Control Projects Identification**</u>

Solutions identification for flood control CIP projects in creeks was performed using the following systematic procedure:

1. Problem Area Identification and Definition - The consultant team was provided with three primary resources for identifying flood problem locations: (1) flood reach problem scores; (2) ArcInfo-based watershed maps with color-coded dots representing flood status for individual structures; and, (3) plots of individual structure flood scores vs. creek station. These resources were used in combination to define individual flood problem areas where a single CIP project can address the flood problem. Flood problem areas frequently encompass more than a single flood problem reach.

2. Problem Area Ranking - Flood problem areas were ranked based upon the combined flood problem scores from the affected reaches in each problem area. Refer to Table 2-3 (in Chapter 2: "Problem Areas Definition and Scoring") for a presentation of the flood problem areas.

3. Selection of Flood Projects for Evaluation in the Protocol - The top sixteen (16) rated flood problem areas were investigated in the solutions selection protocol (as described below) and provided to the feasibility matrix for further evaluation.

Table 4-2: Summary by Watershed of Pond Projects Considered and Selected Using the Water Quality Protocol

Watershed	Abbrev.	No. of Pond Sites Considered	No. of Pond Sites Selected Using Protocol*	Wet Pond, Baseflow & Erosion Capture	Wet Pond & Baseflow	Wet Pond & Erosion Capture	Erosion Capture only	Wet Pond only	Constructed Stormwater Wetlands	Retention-Irrigation
1. Barton Creek	BAR	13	13	0	0	0	0	0	0	13
2. Blunn Creek	BLU	8	4	4	4	4	4	4	0	0
3. Boggy Creek	BOG	9	5	5	5	5	5	5	0	0
4. Bull Creek	BUL	22	11	11	11	11	11	11	0	0
5. Buttermilk Creek	BMK	7	2	2	2	2	2	2	0	11
6. Country Club Creek	CNT	14	11	11	11	11	11	11	0	0
7. East Bouldin Creek	EBO	9	1	1	1	1	1	1	0	0
8. Fort Branch	FOR	14	5	4	4	4	4	4	1	0
9. Harper's Branch	HRP	6	3	3	3	3	3	3	0	0
10. Johnson Creek	JOH	6	2	2	2	2	2	2	0	0
11. Little Walnut Creek	LWA	27	11	11	11	11	11	11	0	0
12. Shoal Creek	SHL	27	11	10	10	10	10	10	3	0
13. Tannehill Branch	TAN	21	12	12	12	12	12	12	0	0
14. Waller Creek	WLR	14	5	5	5	5	5	5	0	0
15. Walnut Creek	WAL	36	13	13	13	13	13	13	0	0
16. West Bouldin Creek	WBO	14	8	8	8	8	8	8	0	0
17. Williamson Creek	WMS	23	17	17	17	17	17	17	0	11
Totals		270	134	119	119	119	119	119	4	35

* Selected Sites are those eligible for evaluation with the Feasibility Level Screening Matrix

Where is the protocol?,

which 22 → 11 ?

and which type???

Flow chart on screening phase

4. Flood Problem Extent Definition - For the top sixteen (16) rated flood problem areas, the associated HEC-RAS flood profiles were plotted and the extent of the flood problem was noted on the watershed map.

5. Flood Site Field Assessments - Each problem site selected for preliminary design was visited in the field to assess the potential for prospective flood solution technologies. Site investigations included assessment of the character of the stream, the local topography, the arrangement of structures, access for channel modifications, and to identify unforeseen significant factors. Upstream of the flood problem area, preliminary reconnaissance was performed for prospective detention sites. Bridges and culverts in the problem areas were evaluated to assess scour and evidence of frequent overtopping.

6. Identification of False Data - Structures reported to be deeply inundated according to the HEC-RAS flood profiles were evaluated in the field to help assess if the flood threat level is real or if aberrations in the modeling procedure were responsible or partially responsible for the extreme level of flooding.

7. Stormwater Detention Assessment - For each flood problem area, stormwater detention (where possible) was assessed. Required flood storage volumes were estimated from flood hydrograph volumes developed using HEC-1 hydrologic models of the watersheds. The required flow rate to solve flood problems in the area was estimated from the stage-discharge relationships through the flood problem area. When adequate flood storage volume is not available, the maximum flood storage volume is provided.

8. Channel Modifications Assessment - For each flood problem area, channel modifications (where possible) were assessed. At four or five representative cross-sections in the problem area, stage-discharge relationships were developed and calibrated using HEC-RAS. Using the stage-discharge relationships, a floodplain bench was excavated (in the computer model) above the level of the 1-year flood with adequate conveyance to reduce the 100-year flood profile below the level of finished floor elevations in the area. When adequate conveyance was not possible, the maximum available conveyance was provided.

9. Bridge and Culvert Modifications - For each flood problem area, an assessment was made of whether modifications to existing bridge and culvert structures could provide significant flood relief. Where possible, the existing bridge or culvert was replaced with a preliminarily-configured structure upgrade providing additional conveyance.

10. Property Acquisition Assessment – Floodplain property buyouts were assessed for all properties within both the 25- and the 100-year floodplains. Property values were obtained using Travis County Appraisal District (TCAD) information. These values were then increased to account for additional costs for acquiring property via condemnation and due to slight undervaluing of property in the TCAD database. Property buyout costs were calculated for both conventional condemnation acquisition and for voluntary buyouts.

11. Assessment of Other Flood Solutions Technologies – Where channel modifications and stormwater detention appeared to be impossible or substantially limited in controlling the problem, alternative structural flood solutions were considered including: (1) flow diversion (channels or tunnels); (2) levees and/or floodwalls; and (3) structure-raising. Levees, floodwalls and structure-raising are considered less desirable from an aesthetic perspective, therefore were considered only when channel modifications and stormwater detention were not possible. The use of flow diversion is often precluded by physical site constraints, thus it was considered only in cases where possible.

12. Technology Selection Protocol - When both channel modifications and flood detention (or other structural solutions) were capable of substantially solving the existing flooding problem, all viable solutions were designed, preliminary costs and benefits estimated, and benefit/cost ratios compared. If no structural solution was capable of solving the flood problem, the flood detention capability or channel conveyance was maximized. If maximum application of the structural flood solutions does not substantially solve the problem, the maximum benefit is derived and evaluated. If the available flood benefits were considered inconsequential, the project was abandoned.

Table 4-3 presents a summary by watershed of the total number of capital flood projects evaluated with the Protocol and the final number and type of projects chosen for evaluation with the Feasibility Matrix.

Protocol for Storm Sewer Flood Projects Identification

The Stormwater Management Division provided the project team with a listing of seventeen (17) storm sewer problem areas for which rehabilitation would be accomplished through the CIP program. Due to the limited nature of this list, all seventeen (17) prospective storm sewer rehabilitation projects were selected for assessment in the storm sewer feasibility matrix. For each storm sewer problem area, Stormwater Management Division staff provided numerical ratings (on a scale of 1-10) for facility condition, system capacity, pipe load bearing capacity, level of required improvements, and structural conflicts. Based upon a compilation of ratings from each category, the 17 storm sewer problem sites were rated. Table 4-4 presents a prioritized listing of the storm sewer problem areas suitable for CIP projects.

4.2.3 Erosion Control Capital Solutions Identification Protocol

Separate solutions identification protocols were developed and implemented for structural bank stabilization measures and for pond-type erosion flow storage controls. Raymond Chan & Associates performed the solutions identification protocols analysis for the structural bank stabilization measures. Loomis & Moore implemented the solutions identification protocols for pond measures.

For erosion management using structural bank stabilization, all of the primary available structural bank stabilization solution types were considered at each problem site. These include in priority order for erosion:

1. Obstruction removal (boulders, vegetation, etc.);
2. Biorevetment - Structural (Reinforced Earth);

Table 4-3: Summary by Watershed of Flood Capital Projects Considered and Selected Using the Flood Protocol

Watershed	Abbrev.	Total Flood Reaches Considered	Total Flood Reaches with Projects	Type of Projects Considered*								
				Property Acquisition	Stormwater Detention	Concrete-Lined Channel	Channelization	Storm Sewer Installations	Storm Sewer Modific.	Bridge & Culvert Replace.	Flood Walls/Levees	Diversion Tunnels
1. Barton Creek	BAR											
2. Blunn Creek	BLU											
3. Boggy Creek	BOG											
4. Bull Creek	BUL											
5. Buttermilk Creek	BMK											
6. Country Club Creek	CNT											
7. East Bouldin Creek	EBO											
8. Fort Branch	FOR											
9. Harper's Branch	HRP											
10. Johnson Creek	JOH											
11. Little Walnut Creek	LWA											
12. Shoal Creek	SHL											
13. Tannehill Branch	TAN											
14. Waller Creek	WLR											
15. Walnut Creek	WAL											
16. West Bouldin Creek	WBO											
17. Williamson Creek	WMS											
Totals		0	0	0	0	0	0	0	0	0	0	0

Note: Information not available at time of document submittal. Will be submitted with Final Report version.

** Structure raising was not considered on a site-by-site basis; only general estimates of structure raising costs were attempted.*

Table 4-4: Listing and Ranking of Top-Rated Storm Sewer Projects Appropriate for CIP Solutions

Problem Area	Facility Problem	Facility Condition	Capacity vs. Storm	Load Bearing Capacity	Required Improve-ments	Structural Conflicts	Problem Score
Colorado Street	Inadequate storm sewer at Intersections. Street reconstruction project imminent	10	8	8	10	10	9.2
Pleasant Valley at Elmont	Major arterial flooding.	10	10	8	3	7	7.99
San Antonio from Nueces @ 16th, up S.A. to MLK	Inadequate, unreinforced storm sewer system. Currently 8x8 Arch	5	5	8	1	5	5.02
San Antonio/Guadalupe alley from MLK north to 23rd	Inadequate 42" RCP	5	8	8	5	10	6.95
Nueces Street (L. Shl Crk. Tunnel)	Old stone arch. Building encroachments.	5	10	8	10	10	8.11
E. 16th bet. San Antonio and Guadalupe	Collapsed line.	10	10	10	10	6	9.4
Lavaca Street (f.TWN, up 1st, up Lav. To 8th)	Inadequate storm sewer system.	10	8	8	10	10	9.2
12th at Lamar	Deteriorating storm sewer	8	9	9	1	10	7.58
15th St SS (Shoal & Waller watersheds)	Road reconstruction project	10	5	8	10	2	7.46
E. 7th, from Concho to Comal SS system	Old deteriorating lines (un-reinforced C.P.)	10	5	7	5	5	6.89
East 9th St. (Brazos - Congress) SS	Bad condition	10	5	7	1	8	6.7
Garden Villa	Needs inlet and storm sewer system.	10	10	1	10	1	6.67
Rutherford @ Grayledge	Needs SS system to replace borrow ditch	5	10	1	10	8	6.27
All SS E. 3rd (Chalmers to R.T.M. to Pedernales)	Old deteriorating lines (un-reinforced C.P.)	10	5	5	5	3	6.15
E. 3rd (R.T.M. to Pedernales)	Collapse at Zavala already!	10	5	7	10	10	8.44
Rio Grande (5-A-75 SS), MLK-26		5	8	7	1	10	6.09
3910 Ridgelea to Idlewild	Pipe in ditch. Erosion. Pipe under house	10	7	1	1	10	6.04

Source: City of Austin Stormwater Management Department, 1998.

3. Biorevetment - Vegetation Only;
4. Land acquisition;
5. Loose Rock Riprap ("Big Rocks");
6. Gabions;
7. Concrete Riprap; and
8. Concrete Walls.

Stormwater detention for erosion control was considered for all potential pond sites. Erosion control components were considered in three of the six pond configurations evaluated at each site. The initial solutions selection protocol for pond-type erosion control measures is described in the water quality protocol (Section 4.2.1).

Solutions identification for erosion control CIP projects was performed using the following systematic procedure:

1. Identification and Prioritization of Problem Areas - Using the prioritization system output from the Watershed Erosion Assessments, problem severity scores for each like reach were ranked for all 199 like reaches. From this score, the priority problem areas were identified.

2. Map Identification and Delineation of Problem Sites for Side Slope Projects - From the watershed erosion assessments, all Type 1, Type 2, and Type 3 erosion problems were placed on 1"=200' topographic maps to facilitate the development of project units; each project unit defined an individual side slope project length and location. Side slope projects were thereby delineated based on the proximity of erosion problems. The sum of each erosion problem type was estimated and recorded into a Feasibility Matrix input file.

3. Verification of Side Slope Projects with Field Data - Topographic maps, stream photographs, and data from the Watershed Erosion Assessments Stream Inventory were reviewed to determine potential constraints and opportunities within an individual side slope project. The following items were identified in each project unit:

- Land availability to acquire easement;
- Utility lines within the stream;
- Steep slopes and/or existing slope problems;
- Primary structures and roadways located on the top of bank;
- Construction access problems;
- Existing channel improvements;
- Critical Environmental Features (wetlands from the National Wetland Inventory);
- Location within a parkland;
- Location within a high quality riparian zone;

- Vegetation/structural obstructions;
- Located with the City limits (Watershed Protection Utility Service Area);
- Upstream land available for a Detention Pond; and
- Existing pond available for retrofit.

4. Site Problem Classification - Utilizing the Watershed Erosion Assessments and the Technical Procedures Manual for the Watershed Erosion Assessments, each side slope project was classified into a project type based on the following classification program:

- Type A - Local control of isolated projects, not a continuous project over two or more reaches.
- Type B - An inter-reach project which managed erosion problems over two or more reaches.
- Type C - Watershed wide improvements such as regional ponds, land density controls, flow regulation by ordinances, and entire stream restoration projects.

5. Stormwater Detention for Erosion Control – Stormwater detention ponds were investigated at all suitable open space locations in the study area. Erosion control components were evaluated at all sites (except Barton Creek, which is considered to have negligible erosion problems). Of the six total pond configurations, five were considered to provide a discernable level of erosion mitigation. The six pond configurations that were investigated were considered to impact erosion as follows:

Configuration	Portion Impacting Erosion Control
Erosion Volume Only	100 percent
Erosion + Wet Pool	Erosion volume only
Erosion + Wet + Baseflow	All of the erosion volume and a portion of the baseflow volume (the average annual percentage empty and available for erosion volume capture)
Wet Pool + Baseflow	A portion of the baseflow volume as described above
Wet Pool Only	No erosion benefit
Retention-Irrigation	50 percent of the storage is assumed to be available on an average annual basis for erosion volume storage

For the TSS (channel erosion) and physical integrity downstream problem elements, stormwater detention and metered release is considered the most effective means of control. The 2-year, 1-year, and 6-month storms are considered to be "channel forming," meaning they literally shape the geometry of the channel. Urbanization in a watershed usually results in increases in flow volume, flow velocity and depth for these events. With urbanization, therefore, channel configurations also change leading to sediment loss and disruption of the physical integrity of the natural stream.

The size of storm event to be controlled by the stormwater detention erosion control solution is considered to be a function of the physical composition of the downstream channel. Four distinct geomorphic channel types were identified in the 17 *Watershed Erosion Assessment* reports developed by Raymond Chan & Associates (Chan & Associates, 1998). These were divided into two distinct groups: (1) alluvial and rock-bed channels; and (2) rock- and structurally-controlled channels. Channels with alluvial banks are more susceptible to erosion and bank loss than those with banks controlled by rock geology or by man-made channel armoring. Channels with high enlargement ratios have a greater need for control of channel-shaping storms to counteract loss of banks, increase in sedimentation, and decreases in physical integrity.

The level of detention for each channel type is also dependent upon the degree of future channel enlargement predicted (a function of geomorphology and predicted future development). This factor is represented as the channel enlargement ratio (the ratio of existing channel enlargement to potential future channel enlargement), and is based upon future land use projections.

The level of detention required was determined from analyses prepared for three erosion studies, *Regulatory Approaches for Managing Stream Erosion, Watershed Erosion Assessments - Technical Procedures*, and the 17 *Watershed Erosion Assessments.* All erosion control pond facilities were sized according to the following criteria:

Alluvial and Rock Bed Channels - These two channel types were classified similarly for detention requirements since some rock bed channel types were shales and hard clays. Since these soils are not as hard as limestone, erosion of the channel bed is expected to be in the same range as alluvial channel erosion. In addition, alluvial armoring of rock bed channels was common and this armor could be displaced by watershed land use changes which could facilitate bank erosion.

Alluvial and Rock Bed Channels

Enlargement Ratio ($E_{R\,ULT}$ / $E_{R\,EXT}$)	**Detention Volume Required**
1.0 - 1.5	6 - month storm
1.5 - 2.0	1 - year storm
> 2.0	2 - year storm

Rock- and Structurally Controlled Channels - Rock-controlled channels are common in the recharge zone streams of west Austin. Hydrologic analysis in the Regulations study indicated that stormwater runoff is minimal for the frequent events up to the 1-year 24-hour storm. Therefore, it is only necessary to manage the larger storm events to limit channel enlargement. Structurally-controlled channels feature structural revetment and were considered to be analogous to rock-controlled channels.

Rock and Structurally-Controlled Channels

Enlargement Ratio ($E_{R\ ULT}$ / $E_{R\ EXT}$)	Detention Volume Required
1.0 - 1.7	none
> 1.7	2 - year storm

The large majority of the reaches in the 17 study watersheds were classified as "alluvial" or "rock bed," thus requiring control even for channels which were relatively stable (having low enlargement ratios).

6. Compilation of Erosion Projects – All data for bank stabilization and stormwater detention projects was recorded in a Feasibility Matrix input file. Table 4-5 presents a summary by watershed of erosion problem areas and projects evaluated using the erosion protocol. Appendix C-1 presents a tabulation of all sites and site parameters considered for analysis in the Feasibility Matrix for side slope projects. Appendix C-2 presents a tabulation of all sites and site parameters considered for analysis in the Feasibility Matrix for erosion pond projects. The projects presented in these appendices were those later considered for analysis in the flood control Feasibility Matrix.

4.2.4 Land Acquisition and Conservation Easement Protocol

Land acquisition and conservation easements can be used for water quality, flood, and erosion benefit. A number of potential acquisition or easement sites were considered for this report. These sites are not presented in this present report to avoid premature speculation as to which properties will be considered; such speculation could hinder future negotiations. However, the basic protocol of site selection is straight-forward and is presented below. The sites identified using this protocol can then be considered for analysis in the Feasibility Level Screening Matrix. More analysis of site characteristics will take place at the Feasibility Matrix stage.

Tracts should be selected for the candidate list based on their possible water quality, flood control, and erosion control benefits, and on the likelihood of effectively reducing current or avoiding future problems. The process should begin with identification of water quality and quantity problems in a particular area and the availability of funding to direct towards land protection efforts. Implicit in this is the assumption that available financial resources will not exceed the amount needed to protect all land with current or future problems, and that priorities will have to be determined based on the potential benefits of each candidate tract.

The area targeted for land acquisition or conservation easement purchase should be defined, at least to the watershed level. The list of candidate tracts should be developed with input from various affected City departments, primarily the Watershed Protection Department, but also including the Parks and Recreation Department and possibly others. All undeveloped or very lightly developed tracts in the target area should be considered, although some may be screened out at an early stage based on the plans and wishes of the landowner. The Protocol can be summarized as follows:

Table 4-5: Summary by Watershed of Side Slope and Pond Projects Considered and Selected Using the Water Quality Protocol

Watershed	Abbrev.	Number of Project Sites Considered		
		Side Slope Projects	Detention Ponds	Total No. of Projects Identified
1. Barton Creek	BAR	6	0	6
2. Blunn Creek	BLU	3	4	7
3. Boggy Creek	BOG	4	2	6
4. Bull Creek	BUL	8	5	13
5. Buttermilk Creek	BMK	2	11	13
6. Country Club Creek	CNT	3	11	14
7. East Bouldin Creek	EBO	5	1	6
8. Fort Branch	FOR	7	4	11
9. Harper's Branch	HRP	1	3	4
10. Johnson Creek	JOH	4	2	6
11. Little Walnut Creek	LWA	6	11	17
12. Shoal Creek	SHL	9	10	19
13. Tannehill Branch	TAN	6	12	18
14. Waller Creek	WLR	6	13	19
15. Walnut Creek	WAL	11	8	19
16. West Bouldin Creek	WBO	4	5	9
17. Williamson Creek	WMS	8	17	25
Totals		93	119	212

1. Uplands Tracts for Water Quality

1. Undeveloped or very lightly developed land in strategic areas;* and
2. No minimum size.
3. Landowner willing to consider transaction.

* "Strategic areas" refers to size, location, and site characteristics qualities discussed in the Feasibility Matrix for Land Acquisition. See Table 5-10.

2. Riparian Buffer Zone Tracts for Water Quality

1. Undeveloped or very lightly developed land adjacent to creeks; and
2. No minimum size.
3. Landowner willing to consider transaction.

3. Riparian Acquisition for Erosion or Flood Hazard Elimination

1. Existing flood or erosion problem on site; and
2. No minimum size.
3. Landowner willing to consider transaction.

The City of Austin Parks and Recreation Department (PARD) has already identified a number of riparian greenbelt areas which it is considering for acquisition as parkland. The same watersheds which offer the greatest opportunity for water quality, erosion, and flood control acquisitions are included in this list of potential parklands: Bull, Walnut, Williamson, West Bouldin, and Boggy Creeks. Figure 4-1 shows the prospective riparian areas currently considered by PARD's "Greenway Initiative," which will be voted on for bond monies in September 1998.

The comprehensive nature of the Walnut, Bull, and Williamson Creek acquisitions is especially favorable from a drainage improvement perspective. These lands are logical candidates for watershed protection measures in that large, contiguous tracts exist which could provide both drainage and public park advantages. However, even smaller tracts in other watersheds could provide both watershed protection and public amenity benefits; conversations with PARD staff for this report indicated that PARD would also be interested in much smaller tracts (e.g., as narrow as 20 feet wide) if such lands provided valuable links between existing, disconnected parklands or provided a pedestrian or bicycle access between existing parklands or trails. Please refer to Section 5 for more information on the factors which rate most favorably in land acquisitions; these factors, including recreational benefits and favorable location (e.g., riparian areas) are considered in the Land and Conservation Easement Acquisition Feasibility Matrix ("Land Matrix").

4.2.5 Integration of Capital Solutions

Multiple procedures were utilized to provide maximum integration of CIP projects across missions. Integration between erosion, water quality and flood measures occurs in several ways:

1. At every prospective pond site (over 130 sites), analyses were performed to assess the benefits of including erosion storage in the facility along with the water quality and baseflow volumes. Whenever possible, the maximum available erosion volume (without exceeding the required erosion volume) was included and the analysis performed. For each of the prospective facility designs, the Summary Matrix derived benefit and benefit/cost values for consistent comparison with other integrated and non-integrated stormwater management facilities.
2. For each erosion measure potentially utilizing channel revetment and stabilization, Raymond Chan & Associates selected projects for inclusion in the erosion control Feasibility Matrix which address not just threatened structures but also bank erosion sites from which substantial channel sediment load is derived. For each of these sites, the water quality benefit (TSS reduction) was assessed and quantified in the water quality Feasibility Matrix, then included in the Summary Matrix as part of the overall benefit and benefit/cost scores.
3. At every prospective erosion/water quality pond site, the downstream flood problem was assessed and quantified. Where it appears possible to provide significant flood relief through flood storage (a function of facility size, drainage area, and proximity to the flood site), the erosion/water quality facility was evaluated for inclusion of a flood storage volume. At these sites, flood storage was considered only when adequate additional flood volume is available to (at a minimum) eliminate flooding for the 25-year event downstream. When this was possible, the flood benefit associated with the integrated facility was assessed in the flood control Feasibility Matrix and included in the Summary Matrix.
4. For each prospective flood channelization project, the presence of existing localized erosion was identified. Channel revetment measures used in the flood channelization project will be selected to eliminate future erosion and channel enlargement. For these projects, the erosion benefit associated with providing flood channelization is assessed in the erosion control Feasibility Matrix and included in the Summary Matrix for the project.
5. The Initial Solutions Selection Protocols select for solutions which promote the objectives of all missions. For example, vegetative channel revetment measures which promote overland flow water quality enhancement are preferred over structural measures which threaten stream physical integrity.

The result of these initiatives is that more than 250 of the approximately 800 CIP projects considered in one or more Feasibility Matrices provide explicitly multiple mission benefits.

4.2.6 Integration with Existing City of Austin Capital Projects

To avoid conflict or duplication with existing City of Austin CIP projects, a review of existing initiatives was performed by the Loomis & Moore project team. Information used to identify existing projects was provided by the Watershed Protection Department. This included three sources: (1) the City of Austin document, "Department of Public Works and Transportation – IQ – Project Status Report (December 31, 1997); (2) a map entitled, "Watershed Protection Department Projects" (with index) which locates approximately 140 erosion, flood, and water quality CIP projects across Austin; and (3) CIP project budgeting sheets for very recent projects, some of which were not included in the December 31 document.

From each document, the project team reviewed the character, location, and status of each chronicled existing COA project. The purpose of this investigation was to coordinate existing COA projects with those identified and reviewed by the Loomis & Moore team. This review resulted in several changes to the CIP projects developed by the consultant team including:

1. The Bartholomew Park pond suggested to be located in the upper portion of the park was moved to correspond to the erosion control facility preliminarily designed and located by the City in the lower portion of the park.

2. Espey-Huston's design for the proposed wet pond located at the northeast corner of Mopac and Hwy 183 was included in the feasibility matrix instead of the preliminary design developed for the site by Loomis & Moore.

3. The design for the flood and water quality facility proposed to be placed on St. Edward's University property in the East Bouldin watershed was included in the feasibility matrix instead of the preliminary design developed by Loomis & Moore.

4. The projected multi-mission pond facility located on Little Walnut Creek upstream of Duval Road was identified as an existing Regional Stormwater Management Program facility. Thus, it was considered only for permanent wet pool retrofit.

5. The proposed multi-mission pond facility located on Tar Branch at Metric Boulevard was identified as an existing Regional Stormwater Management Program facility. Thus, it was considered only for permanent wet pool retrofit.

In general, City CIP projects identified as completed were not considered in the Loomis & Moore investigation with one exception. Existing regional flood control facilities were considered for permanent pool water quality retrofit only (with the wet volume excavated from below or adjacent to the flood volume). No hydrologic or hydraulic investigations were implemented to determine if existing flood, water quality, or erosion control facilities or projects are performing inadequately, and are thus candidates for rehabilitation or
This kind of systematic investigation is included as a recommended program (see S
____).

Table 4-6 presents a listing of existing, prospective capital improvement projects developed by the Watershed Protection Department which are currently in the planning or design phase. This table notes the status of each project with respect to the Integrated Solutions Development process.

Table 4-6: Summary of ISD Status of Capital Improvement Projects Currently Planned by the Watershed Protection Department

Project Name	Designer	Type	Watershed	Description and ISD Status
1. Bartholomew Erosion Control Pond	Raymond Chan & Assoc.	Erosion	Tannehill	Project adjusted in ISD model to correspond to City of Austin pond.
2. Beckett Meadows	Espey-Padden	Water Quality	Williamson	This project is a retrofit of existing failing sedimentation and filtration facilities. It was not considered in the ISD process.
3. Betty Cook Pond	Watershed Protection Division (In-House)	Water Quality	Little Walnut	This project is a retrofit of an existing wet pond that is to be excavated to provide additional permanent water quality volume. Not considered in ISD because it is an existing facility.
4. E. Bouldin Erosion Project @ W. Annie	Raymond Chan & Assoc.	Erosion	East Bouldin	Project will replace failed retaining wall and provide protection for a residence. Included in Project Unit EBO-3 in ISD.
5. Erosion Control Group 7 (Little Walnut)	R.J. Brandes/Murfee Eng.	Erosion	Little Walnut	Various erosion revetment projects in Little Walnut Creek. Included in the LWA project units in ISD.
6. Erosion Control Group 8	Santos & Assoc.	Erosion	Various	Various erosion revetment projects in various watersheds. Design complete. Included in various erosion project units in ISD.
7. Erosion Control Group 8	Raymond Chan & Assoc.	Erosion	Various	Various erosion revetment projects in various watersheds. Design complete. Included in various erosion project units in ISD.
8. Evergreen Ave. Storm Sewer Improvements	Watershed Protection Division (In-House)	Flood	W. Bouldin	Construction of 480' of box culvert with storm sewer laterals. Not included on Stormwater Management Division's CIP list.
9. Fort Branch Truelight Baptist Church	Watershed Protection Division (In-House)	Erosion	Fort Branch	Repair of channel erosion downstream of Fort Branch Blvd. Included in project unit FOR-3.
10. Fort Branch, Ph. 3 Culv. And Channel Imps.	Engin. Consult. Service	Flood	Fort Branch	3400 feet of culvert replacement and channel improvements to remove 23 homes from floodplain in vicinity of Manor Road and 51st Street. Currently on hold pending redesign. Ignored in ISD because it is an existing planned proj.
11. Fort Branch, Ph. 4 Culv. And Channel Imps.	Engin. Consult. Service	Flood	Fort Branch	2550 feet of culvert replacement and channel improvements to remove 21 homes from floodplain in vicinity of Westminster Dr. and Rogge Ln. Currently on hold pending redesign. Ignored in ISD because it is an existing planned project.
12. IH 35 and Ben White Water Quality Imps.	R.J. Brandes	Water Quality	Williamson	Multiple water quality facilities to treat additional runoff from intersection improvements at IH 35 and Ben White. Ignored in ISD due to ongoing project.
13. Lampassas Trail Regional Stormwater Pond	Not Determined	Flood, Water Quality, Erosion	Bull	Regional flood control facility to be retrofit with erosion, water quality and baseflow elements. This was a high priority recommendation from the ISD project included in 1998 CIP.

Table 4-6: Summary of ISD Status of Capital Improvement Projects
Currently Planned by the Watershed Protection Department

Project Name	Designer	Type	Watershed	Description and ISD Status
14. Little Walnut Erosion Cntl Ph. 8 - Auburndale	R.J. Brandes	Erosion	Little Walnut	Streambank erosion control for several homes along Auburndale Dr. and Dottie Jordan Park. Design on hold pending neighborhood deliberations. Included in ISD project unit LWA-2.
15. Little Walnut Ck WQ Pond at Rundberg Ln.	Espey-, Huston & Assoc.	Water Quality	Little Walnut	Completed extended detention WQ facility will be considered in ISD for expansion and addition of erosion and additional WQ control.
16. Lower Shoal Creek Erosion Project	Raymond Chan & Assoc.	Erosion	Shoal	Will include a rigorous channel assessment between 12th St. and 29th St. to identify erosion projects. Currently in the study phase. Included in ISD project units SHL-2 and SHL-3.
17. Little Walnut Ck Erosion Ph. 7 - Lakeside	R.J. Brandes/Murfee Eng.	Erosion	Little Walnut	Bioengineering and gabions to protect 2 homes. Currently under design. Included in ISD project unit LWA-1.
18. Little Walnut Eros. Cntrl Ph. 3 - Bridgewater	R.J. Brandes	Erosion	Little Walnut	Stacked rock and bioengineering to protect Bridgewater Dr. and adjacent homes. Project currently under design. Not included in ISD analysis.
19. Mabel Davis Pond Retrofit	Radian	Water Quality	Country Club	Project is for retrofit of existing pond site to water quality. Evaluated in ISD for all combinations of erosion, WQ, and baseflow.
20. Oak Hill Regional Flood Detention Facility	CDM	Flood	Williamson	Regional flood control facility to be located in upper Williamson Creek watershed. Project designed and currently in ROW phase. Evaluated in ISD for additional WQ and erosion benefits.
21. Shipe Park Erosion Control	Watershed Protection Division (In-House)	Erosion	Waller	Channel revetment through Shipe Park using various technologies. Design 95% complete. Not included in ISD due to virtual completion of project.
22. Shoal Creek Erosion Control at 4th Street	Raymond Chan & Assoc.	Erosion	Shoal	350 feet of streambank stabilization behind Strait Music. In preliminary design. Included in ISD project unit SHL-1.
23. South Congress Detention Pond	RMI	Flood	East Bouldin	Flood detention pond in Gillis Park watershed. Currently in design. Evaluated in ISD for WQ.
24. St. Edwards Pond	RMI	Flood, Water Quality	East Bouldin	Combination flood/wet pond on St. Edward's Univ. campus. Currently awaiting easement acquisition. Evaluated in ISD analysis for erosion and water quality.
25. Storm Sewer Improvement Group 1	Watershed Protection Division (In-House)	Flood	Various	Construction of new storm sewer facilities at various locations to reduce threat of urban flooding. May be completed. Not included in ISD because not put on CIP list by Stormwater Management.
26. Tannehill Br. at MLK Channel Improvements	Raymond Chan & Assoc.	Flood	Tannehill	Channel improvements MLK to 12th Street. Not included in ISD analysis due to its being an existing project.
27. Tannehill/Fort Br. Erosion Group 5	Raymond Chan & Assoc.	Erosion	Tannehill/ Fort Branch	Gabions and biorevetment for stabilization of eroded creek banks at 5 sites. Included in multiple ISD project units.

Table 4-6: Summary of ISD Status of Capital Improvement Projects Currently Planned by the Watershed Protection Department

Project Name	Designer	Type	Watershed	Description and ISD Status
28. Upper Shoal Creek Detention/WQ Retrofit	Espey, Huston & Assoc.	Flood, Water Quality	Shoal	Retrofit of existing driving range flood control facility for water quality (wet pond). Project to be constructed soon. Considered in ISD as a stormwater wetlands.
29. Waller Creek Detention Pond at Hancock GC	Raymond Chan & Assoc.	Flood	Waller	Flood detention pond at Hancock Golf Course. Project design on hold pending funding decision. Not considered in current ISD due to low flood problem score.
30. Waller Creek Detention Pond at Reilly Elem.	Raymond Chan & Assoc.	Flood	Waller	On-line flood detention at Reilly Elementary. Currently on hold. Considered in ISD as an offline facility with superior performance, but apparently logistical contraints have dictated the current Chan design.
31. Waller Creek Retaining Wall Repair, Ph 1	RMT/Jones & Nuese	Erosion	Waller	50 feet of mortared rock wall replacement. Project nearly complete. Not considered in ISD.
32. Waller Creek Retaining Wall Repair, Ph 1	RMT/Jones & Nuese	Erosion	Waller	80 feet of mortared rock wall replacement. Project bid in December, 1997. Not considered in ISD.
33. Walnut Creek Detention Facility at Yett Creek	Gebhard-Sarma	Flood, Erosion	Walnut	Regional flood and erosion control facility. Project is complete but has been evaluated for water quality retrofit in ISD. Other pond sites in area have been evaluated in ISD.
34. Westover Hills Storm Sewer Improvements	Raymond Chan & Assoc.	Flood	Shoal	3,000 feet of storm sewer replacement and improvement on Tallwood Drive. Awaiting easement acquisition. Not included on Stormwater Management's CIP storm sewer list.
35. White Horse Trail Culvert Improvements	Raymond Chan & Assoc.	Flood	Shoal	Replacement of existing 36 inch RCP with 2-7'x3' box culverts. Design complete. Not included in current ISD work due to its being an existing project.
36. Detention Ponds at Various Locations	Various	Flood	Various	Dick Nichols Park, Oak Hill, and Waller Creek stormwater management ponds. Dick Nichols and Oak Hill considered in ISD for water quality (permanent pool) retrofit.
37. Thrushwood Drive Stowmwater Mgmt. Pond	???	Flood??	Shoal	Unknown
38. Waller Creek Bank Erosion Improvements	Not Determined	Erosion	Waller	Cesar Chavez to 9th St. bank stabilization improvements. Currently awaiting design. Funded through Proposition 1. Not considered in ISD due to its inclusion in Waller Creek project.
39. Crystal Brook Flood Improvements	Not Determined	Flood, Erosion	Walnut	Construction of flood and erosion improvements at Crystal Brook and Lake Loomis. Funded through Proposition 3. Projects developed during ISD project high priority phase.

4.3 SOLUTIONS SELECTION PROTOCOLS FOR REGULATIONS

[insert text]

4.3.1 Flood Control Regulatory Solutions Identification Protocol

[insert text]

4.3.2 Water Quality Regulatory Solutions Identification Protocol

[insert text]

4.3.3 Erosion Control Regulatory Solutions Identification Protocol

[insert text]

4.4 SOLUTIONS SELECTION PROTOCOLS FOR OPERATING PROGRAMS

[insert text]

4.4.1 Flood Control Operating Programs Solutions Identification Protocol

[insert text]

4.4.2 Water Quality Operating Programs Solutions Identification Protocol

[insert text]

4.4.3 Erosion Control Operating Programs Solutions Identification Protocol

[insert text]

5.0 Solutions Feasibility and Effectiveness Screening

Feasibility level screening matrices ("Feasibility Matrices") were developed to assess the effectiveness of the prospective capital, programmatic, and regulatory solutions identified through implementation of the Solutions Protocols. The Feasibility Matrix investigations were used: (1) to allow for objective comparison of individual solutions; and (2) to support definition of the specific ability of each solution or combination of solutions to meet the Watershed Protection Department's Interim Management Goals.

For each solution type, separate Feasibility Matrices were developed to evaluate specific solutions (capital improvement projects, regulations, and programs) as means for managing each problem type (flood, water quality, and erosion). Normalized scores derived from these multiple Feasibility Matrix applications were combined into a final summary Feasibility Matrix ("Summary Matrix") to allow for direct comparison of differing solution measures. Discussion of the Summary Matrix is presented in this section. Discussions of the individual Feasibility Matrix applications (supporting the Summary Matrix) for each problem and solution type are presented in Sections 5.1 through 5.3.

Each individual solution was given an effectiveness score for water quality, flood control, and erosion control. These scores were normalized on a 100-point scale with the top-scoring solution assigned the 100 value. For example, the water quality Feasibility Matrix for CIP solutions uses a scale of 0-100 to describe the value of CIP Project X as a water quality management measure. The Flood Control Feasibility Matrix for regulatory solutions describes on a scale of 0-100 the value of Regulation Y as a flood management measure. In the Summary Matrix, these normalized scores are inserted in the appropriate column (water quality, flood control, or erosion control). In many cases, a particular solution may have benefits for more than one problem type. For example, a water quality pond may have a normalized water quality score of 55, a normalized erosion score of 26, and a flood control score of 0.

Summary Matrix

In the Summary Matrix, projects are measured by two standards: (1) technical effectiveness and (2) cost-effectiveness. For each solution, benefit values are defined as the weighted sum of the individual normalized benefit values associated with the three problem types:

1. Water Quality Control Effectiveness
2. Flood Control Effectiveness
3. Erosion Control Effectiveness

Weightings of the problem types were derived from City public polling data measuring citizen preferences and opinions regarding drainage infrastructure priorities (Section 2.4). Estimated costs (initial and ongoing) are specified as the present value of the total capital cost and ongoing operations and maintenance expenditures.

In addition to the problem effectiveness scores, a score is presented representing each solution's "sustainability." The sustainability score is weighted at a maximum of 10 percent of the overall benefits score and reflects: (1) compatibility with existing City projects and (2) neighborhood impact.

Development of Sustainability Scores

Sustainability scores are based upon the two parameters listed above:

1. Compatibility with Existing City Projects – a function of degree of coordination and consolidation of services, synergy, and shared operating system benefits;
2. Neighborhood Impact – a function of ability to preserve or add heritage value, the degree to which the site is utilized and accessible, and the opportunity for recreational and educational use by the public.

Each sustainability factor is weighted at 50% (5% of the total benefits score). Scoring criteria utilized for each parameter are presented below:

Compatibility with Existing City Projects

Percent of Possible Score Achieved	Parameter Value
100%	Project completion necessary for a related project underway
80%	Project completion necessary for a related scheduled project
60%	Plans laid out for utilization of synergistic opportunities
20%	Project offers synergistic opportunities
10%	Project can not/does not affect any other projects positively
0%	Project would negatively impact another project's completion

Neighborhood Impact

Percent of Possible Score Achieved	Parameter Value
100%	Very high positive impact
80%	High positive impact
60%	Moderately positive impact
20%	Low positive impact
10%	Neutral impact
0%	Negative impact

Factors considered in developing the impact rating for Neighborhood Impact include:

1. Heritage Value
   - impact on property values
   - compatibility with existing development
   - aesthetics
2. Utilization Potential/Accessibility
3. Recreation Potential
4. Educational Potential

Scores assigned for the 13 types of CIP solutions considered are as follows:

Approach	Score	
	Neighborhood Impact	Compatibility with Other Projects
1. Irrigation	10%	*[Not Considered with this draft submittal]*
2. Baseflow + Erosion + Wet Retention	60%	
3. Erosion Storage Only	10%	
4. Erosion + Wet Retention	60%	
5. Baseflow + Wet Retention	80%	
6. Wet Retention Only	80%	
7. Flood Detention Offline	100%	
8. Flood Detention Online	20%	
9. Erosion Side Slope Treatment	10%	
10. Flood Channelization	0%	
11. Buyouts for Flood or Erosion Control	60%	
12. Land/Conservation Easement Acquisition	100%	
13. Grassed Swales	10%	

The Summary Matrix presents sustainability scores for each of the flood, water quality, and erosion CIP projects. The results of the Summary Matrix evaluation are presented in Table 5-11 (Section 5.4).

5.1 Feasibility Matrix Development for CIP Solutions

For CIP solutions, individual feasibility level screening matrices were developed for each problem type (water quality, flood, and erosion). A separate Feasibility Matrix screening tool was developed for land acquisition and conservation easement solutions. The feasibility matrices provide normalized effectiveness scores (on a scale of 0-100) describing the relative value of each specific solution's ability to solve the corresponding problem type. Descriptions of Feasibility Matrix development for CIP solutions to flood, water quality, and erosion problems are presented below:

5.1.1 Water Quality Feasibility Matrix Development for CIP Solutions

For each CIP solution application site, six combinations of water quality control measures were evaluated in the Water Quality Feasibility Matrix ("WQ Matrix"). These include:

1. Permanent wet pool, erosion detention, and baseflow detention;
2. Erosion detention only;
3. Permanent wet pool only (wet ponds and constructed wetlands);
4. Permanent wet pool with baseflow detention;
5. Permanent wet pool with erosion detention; and
6. Retention-irrigation.

For each water quality technology combination from this list, the WQ Matrix derives a quantitative benefit value at each prospective capital project site. Benefits are measured in units of "Problem Score" points.

Each of the study area's 70 EII reaches is assigned a Problem Score (see discussion in Section 2.1.1 and in this Section below). The Problem Score value reflects the degree of water quality concern in the EII reach. Problem Scores were derived from a compositing of water quality parameter values compiled for the subject reach through office, field, and laboratory investigations performed by City staff. The water quality elements of the EII reach Problem Score include:

- TSS load from the uplands;
- TSS load from the channel;
- Nutrients load;
- Toxics load;
- Spills risk;
- Baseflow quantity; and
- Physical integrity.

Each of the above seven water quality parameter values is associated with a portion of each EII reach's total Problem Score. The relative portion of the EII score assigned to each water quality parameter was derived by City staff from office, field, and laboratory investigations for current problems and from the CRWR Parsimonious Model for future problems. Apportionment percentages for existing conditions TSS load between uplands and channel was also derived from the CRWR model.

The Problem Score value assigned to each water quality parameter (its portion of the overall EII reach Problem Score) is considered to represent the magnitude of that element of the overall water quality problem in that reach. Benefit associated with the application of a CIP solution is reflected by reducing the Problem Score value in the relevant EII reaches. The units of benefit are thus Problem Score points. The amount of benefit (Problem Score reduction) engendered for each water quality problem element by a particular CIP solution is calculated using three capital solution effectiveness parameters:

1. Pollutant load (or problem) reduction effectiveness (a function of the pollution reduction abilities associated with the particular technology);
2. The portion of a watershed's problems treated by the particular project (a function of the BMP's position in the watershed);
3. The percentage of flow in the project's drainage area captured or treated by the solution (a function of BMP size with respect to the contributing watershed area and imperviousness).

The overall water quality benefit derived from each prospective CIP solution is calculated to be the sum of the individual water quality problem element score reductions for current and future conditions in all affected EII reaches. Final scores used to rank the individual solutions were calculated for total benefit to the watershed.

Problem Score Points as Unit of Measure for Reaches and Watersheds

Individual Problem Score values were derived by City staff for each of the 70 EII reaches and for both current and future watershed conditions. The final rank score value for an EII reach is a composite of normalized Problem Scores assigned to each EII reach for each of the seven water quality problem elements (nutrients, physical integrity, TSS, etc.) making up the Problem Score. As discussed in Section 2.1, Problem Score values also reflect the amount of flow each EII reach contributes to Austin's receiving waters (Town Lake, McKinney Falls, etc.), each of which is assigned a resource value.

Problem Score points were chosen as the unit of measure for problem severity and magnitude of benefits because they enable the consistent comparison of varying types of problems and solutions. Consistency of units for disparate problems with differing units of measure (e.g., baseflow (cfs) vs. toxics load (lbs/yr) is achieved through normalization of the individual problem element scores prior to compilation of the overall Problem Score.

Problem Score points also reflect the magnitude of the water quality problems assigned by the City to each EII reach. The extent to which a solution addresses the highly scored components of its Problem Score determines the solution's overall score in the WQ Matrix and reflects the value of implementing the solution. Thus, if an EII reach has a high Problem Score (indicating that it is or will be an area of concern) because of insufficient baseflow, a solution which can enhance baseflow meaningfully in the present and future would receive a favorable rating. Conversely, a solution which does not address either the significant problems of concern in a highly-ranked area or which resolves problems in a low-ranked reach would not receive as high a score.

Assumed Constituent Removal Efficiencies for Pond and Swale BMPs

BMP	Sediment TSS	Nutrients DP	Toxics/Spills COD
Retention-Irrigation	81%	81%	81%
Wet Pond*	43-82%	38-66%	11-70%
Constructed Stormwater Wetlands*	43-82%	38-66%	11-70%
Sedimentation/Sand Filtration	68%	0%	52%
Ext. Detention for Baseflow, Flood Control	40%	0%	24%
Grassed Swale	40%	0%	24%

** Removal efficiency dependent upon the VB/VR ratio; larger facilities have the best removal rates.*

Downstream Problem Control: TSS and Physical Integrity

For the TSS and physical integrity downstream problem elements, determinations were made in the Water Quality Protocol as to the erosion control capture volume required of each pond BMP. These calculations are based upon the upstream drainage area, the future conditions runoff coefficient, the design rainfall volume, and the runoff volume assuming 10 percent impervious cover. The following table illustrates the method used to calculate the design storm volumes:

Method for Calculating Design Storm Capture Volumes

Return interval to be controlled	Inches of Rainfall*		Future Runoff Coefficient		Drainage Area of Basin		Volume with 10% IC		Volume for Capture
6-month	1.224	x	Rv**	x	D.A.	–	10% IC vol.	=	Volume
1-year	1.930	x	Rv**	x	D.A.	–	10% IC vol.	=	Volume
2-year	2.639	x	Rv**	x	D.A.	–	10% IC vol.	=	Volume

*Data for Austin rainfall events for the 3-hour design storm.
*Function of impervious cover

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As seen in the above table, the pre-developed conditions runoff volume that is subtracted from the future conditions runoff volume assumes 10 percent impervious cover instead of completely undeveloped conditions. This assumption is based upon research indicating that appreciable, negative effects on water quality and creek systems do not begin to be evident until a basin develops above approximately the 10% impervious cover level (Schueler, 1995).

The percent effectiveness of a particular CIP solution is assumed to vary linearly from zero (no capture) to 100 percent (full capture of the required storm runoff volume). Capture volumes above the required capture volume do not receive extra benefit score.

Downstream Problem Control: Baseflow

For the baseflow problem element, extended detention with slow release was assumed to be the most effective and direct means of enhancing baseflow volumes and flow rates. Other CIP solution types, such as retention-irrigation, are considered capable of only marginal baseflow enhancement benefit on a single project basis. Therefore, no baseflow credit was assigned for infiltration practices. ?

To correlate baseflow yield (average annual flow rate increase) with baseflow detention volume, the consultant team developed a spreadsheet-based hydrologic accounting tool. This program predicts the long term pond outflow record for a given rainfall input, baseflow storage volume, and outflow structure configuration. The rainfall input was a 10-year record of City of Austin rainfall (1984 to 1994). Average annual flow rate is calculated directly from the outflow record.

The baseflow enhancement effectiveness of a given extended detention facility is measured as its ability to meet City-defined, minimum baseflow goals. Based ~~upon City~~ of Austin research on the rate of baseflow per acre of watershed~~, the City~~ established different minimum goals for different creek systems. Urban, suburban, and rural watersheds were assigned baseflow goals as presented below: for this EII s

City of Austin Baseflow Goals for Urban, Suburban, and Rural Watersheds

Watershed	Baseflow Goal
Urban*	0.0002 x cfs/acre or maintain current baseflow, whichever higher
Suburban**	0.0004 x cfs/acre or maintain current baseflow, whichever higher
Rural***	0.0006 x cfs/acre or maintain current baseflow, whichever higher

* Blunn, Boggy, Buttermilk, East Bouldin, Fort Branch, Harper's Branch, Johnson, Shoal, Tannehill Branch, Waller, West Bouldin

** Country Club, Little Walnut, Walnut, Williamson

*** Barton, Bull

Using the baseflow storage volume, each CIP solution with extended detention for baseflow was assigned an "additional baseflow yield" (cfs) to be added to the creek downstream of the facility. The enhanced baseflow for each EII reach was compared with the baseflow goal for that creek. The percentage of the goal achieved was used as the assumed percentage effectiveness for baseflow enhancement. No extended detention facility was attributed with more than 100% effectiveness, no matter how high its baseflow contribution.

<u>Effectiveness Reductions due to CIP Solution Location</u>

The effectiveness of an individual CIP solution is dependent upon its position in the watershed. Water quality ponds located in the upper watershed cannot control runoff flows generated in the lower watershed. Similarly, ponds located in the lower portion of the basin cannot provide protection for the creek upstream. The WQ Matrix adjusts each solution's effectiveness score to reflect a reduction in effectiveness due to the CIP solution's location in the watershed.

The WQ Matrix accounted for whether the BMP was located on the *main branch* (as defined by the EII reaches) or on a *tributary* of the main branch. Main branch locations allowed the treatment of water (and pollutants) from other upstream EII reaches. Tributary locations could only treat uplands flows from that same EII reach. Both could help with in-channel problems in other downstream EII reaches.

Adjustments in effectiveness due to location were made by reducing the EII reach Problem Score points proportionately to the area not benefited by the BMP. A CIP solution that does not have access to a portion of the watershed loses the ability to reduce the Problem Score points for the inaccessible EII reaches or portions of reaches. Thus, if a BMP is located 50% of the way down a given EII reach, then it could only be eligible to receive 50% of the Problem Score points for a given problem type for that reach. For example, baseflow storage facilities can not provide baseflow enhancement upstream of the BMP. Pond and swale BMPs located on tributaries are not eligible to receive credit for load (or Problem Score point) reductions from upstream EII reaches which, by definition, they cannot control. Spills prevention measures are not eligible to provide spills protection for creek segments upstream of the spills capture facility.

Effectiveness Reductions due to Limitations in CIP Solution Capture Volume

The effectiveness of a pond-type capital solution is limited by its ability to store and treat runoff. The WQ Matrix accounts for flows which cannot be treated by estimating the portion of the average annual runoff which the pond will capture and treat. The remainder was assumed to bypass the BMP and go untreated. The effectiveness of a given pond solution (measured in Problem Score point reduction) was adjusted by multiplying the Problem Score reduction value by the percentage of the average annual runoff captured in the facility.

The average annual runoff capture percentage was calculated based upon: (1) the distribution of rainfall event sizes in Austin derived from a 30-year record of Austin rainfall; (2) the runoff characteristics of the contributing watershed (size, impervious cover); and, (3) the capture volume of the facility. Effectiveness reductions due to limitations in the runoff capture volume were applied only for upstream problem elements treated in a pond facility (uplands TSS load, upstream channel TSS load, nutrient load, and toxics load).

Results of the Feasibility Matrix Application for Water Quality Projects

A total of 634 pond configurations at 140 sites identified using the Protocol were evaluated using the WQ Matrix. Table 5-1 presents the top 40 most effective pond configurations for capital water quality solutions. Table 5-2 presents the top 40 most *cost*-effective pond configurations for capital water quality solutions. Appendix A-3 presents a complete listing of the scores, costs, and cost-effectiveness calculations for all capital water quality solutions evaluated. These normalized scores are those included in the Summary Matrix. Figure 5-1 illustrates how the WQ Matrix scores an example capital improvement project.

Table 5-1: Top 40 Most Effective Pond Configurations for Capital Water Quality Solutions*

Rank	Pond No.	Wshed	Location	BMP Type	WQ Score
1.	**111a.**	**WAL**	**Walnut Creek Metro Park**	**Wet + BF + Eros**	**100.00**
2.	111c.	WAL	Walnut Creek Metro Park	Wet + Eros	66.65
3.	111b.	WAL	Walnut Creek Metro Park	Eros capt	65.80
4.	**110a.**	**WAL**	**N. of Criswell & Sprinkle Rd., along creek**	**Wet + BF + Eros**	**64.76**
5.	110b.	WAL	N. of Criswell & Sprinkle Rd., along creek	Eros capt	59.68
6.	110c.	WAL	N. of Criswell & Sprinkle Rd., along creek	Wet + Eros	52.16
7.	**131f.**	**WMS**	**S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)**	**Irrig.**	**50.94**
8.	**27f.**	**BUL**	**W. of Old Lampasas Trail, N. of creek**	**Irrig.**	**41.71**
9.	111d.	WAL	Walnut Creek Metro Park	Wet + BF	41.65
10.	**122f.**	**WMS**	**Covered Bridge**	**Irrig.**	**39.54**
11.	**99a.**	**WBO**	**Trailer Park between Oltorf & Flanigan Cove**	**Wet + BF + Eros**	**37.05**
12.	110d.	WAL	N. of Criswell & Sprinkle Rd., along creek	Wet + BF	34.24
13.	**97a.**	**WBO**	**South Center St. and Audrey Ct.**	**Wet + BF + Eros**	**33.30**
14.	99d.	WBO	Trailer Park between Oltorf & Flanigan Cove	Wet + BF	33.08
15.	**124f.**	**WMS**	**NW of HEB @ Hwy. 290/71**	**Irrig.**	**32.91**
16.	131b.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Eros capt	30.32
17.	**17a.**	**BLU**	**N. of Oltorf in Nature Pres.**	**Wet + BF + Eros**	**27.80**
18.	122a.	WMS	Covered Bridge	Wet + BF + Eros	27.30
19.	**112a.**	**WAL**	**SW of Duval Rd. & S-bound MoPac**	**Wet + BF + Eros**	**26.98**
20.	27b.	BUL	W. of Old Lampasas Trail, N. of creek	Eros capt	26.81
21.	**56a.**	**JOH**	**NE of L. Austin Blvd./MoPac/Cesar Chavez interchange**	**Wet + BF + Eros**	**25.63**
22.	56c.	JOH	NE of L. Austin Blvd./MoPac/Cesar Chavez interchange	Wet + Eros	25.32
23.	124b.	WMS	NW of HEB @ Hwy. 290/71	Eros capt	25.18
24.	27a.	BUL	W. of Old Lampasas Trail, N. of creek	Wet + BF + Eros	25.03
25.	56d.	JOH	NE of L. Austin Blvd./MoPac/Cesar Chavez interchange	Wet + BF	24.93
26.	56e.	JOH	NE of L. Austin Blvd./MoPac/Cesar Chavez interchange	Wet pool	24.86
27.	131a.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Wet + BF + Eros	24.06
28.	99b.	WBO	Trailer Park between Oltorf & Flanigan Cove	Eros capt	23.47
29.	**25f.**	**BUL**	**Sierra Blanca & Centennial Trail**	**Irrig.**	**23.33**
30.	**104a.**	**WAL**	**SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)**	**Wet + BF + Eros**	**23.13**
31.	131c.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Wet + Eros	22.55
32.	**55d.**	**JOH**	**Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield**	**Wet + BF**	**22.53**
33.	**14a.**	**BLU**	**St. Ed's along creek**	**Wet + BF + Eros**	**22.30**
34.	55e.	JOH	Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield	Wet pool	21.66
35.	97d.	WBO	South Center St. and Audrey Ct.	Wet + BF	21.60
36.	27c.	BUL	W. of Old Lampasas Trail, N. of creek	Wet + Eros	21.38
37.	**29b.**	**BUL**	**SW of Old Lampasas Trail & Spicewood Springs Rd.**	**Eros capt**	**20.90**
38.	**15a.**	**BLU**	**St. Ed's to Alpine**	**Wet + BF + Eros**	**20.37**
39.	55c.	JOH	Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield	Wet + Eros	20.03
40.	55a.	JOH	Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield	Wet + BF + Eros	19.66

* Bolded facilities indicate the highest ranked configuration for a particular site; non-bolded facilities have a higher rated configuration also shown in this table.

Table 5-2: Top 40 Most Cost-Effective Pond Configurations for Capital Water Quality Solutions*

Rank	Pond No.	Wshed	Location	BMP Type	WQ Score	Capital Cost	Effect/Cost x 1,000,000
1.	**27b.**	**BUL**	**W. of Old Lampasas Trail, N. of creek**	**Eros capt**	**26.81**	**$ 455,999**	**58.80**
2.	**122b.**	**WMS**	**Covered Bridge**	**Eros capt**	**17.27**	**$ 348,817**	**49.51**
3.	**131b.**	**WMS**	**S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)**	**Eros capt**	**30.32**	**$ 620,199**	**48.88**
4.	**25b.**	**BUL**	**Sierra Blanca & Centennial Trail**	**Eros capt**	**11.80**	**$ 278,999**	**42.30**
5.	**17b.**	**BLU**	**N. of Oltorf in Nature Pres.**	**Eros capt**	**15.63**	**$ 391,413**	**39.93**
6.	**85b.**	**TAN**	**Lower end of Bartholemew Park**	**Eros capt**	**7.88**	**$ 200,704**	**39.24**
7.	**97b.**	**WBO**	**South Center St. and Audrey Ct.**	**Eros capt**	**14.27**	**$ 371,521**	**38.42**
8.	27f.	BUL	W. of Old Lampasas Trail, N. of creek	Irrig.	41.71	$ 1,134,182	36.78
9.	17a.	BLU	N. of Oltorf in Nature Pres.	Wet + BF + Eros	27.80	$ 759,328	36.62
10.	**16d.**	**BLU**	**N. of Alpine**	**Wet + BF**	**11.92**	**$ 329,593**	**36.17**
11.	**55e.**	**JOH**	**Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield**	**Wet pool**	**21.66**	**$ 604,708**	**35.81**
12.	16a.	BLU	N. of Alpine	Wet + BF + Eros	14.87	$ 417,247	35.64
13.	122f.	WMS	Covered Bridge	Irrig.	39.54	$ 1,115,624	35.44
14.	55b.	JOH	Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield	Eros capt	12.44	$ 363,833	34.19
15.	**124b.**	**WMS**	**NW of HEB @ Hwy. 290/71**	**Eros capt**	**25.18**	**$ 753,487**	**33.42**
16.	97a.	WBO	South Center St. and Audrey Ct.	Wet + BF + Eros	33.30	$ 1,042,877	31.93
17.	25f.	BUL	Sierra Blanca & Centennial Trail	Irrig.	23.33	$ 737,102	31.65
18.	17d.	BLU	N. of Oltorf in Nature Pres.	Wet + BF	15.99	$ 515,925	30.99
19.	122a.	WMS	Covered Bridge	Wet + BF + Eros	27.30	$ 913,052	29.89
20.	124f.	WMS	NW of HEB @ Hwy. 290/71	Irrig.	32.91	$ 1,146,629	28.70
21.	**28b.**	**BUL**	**Spicewood Springs, Old Lampasas; gravel road on R @ 100 oaks**	**Eros capt**	**4.51**	**$ 159,495**	**28.26**
22.	**14b.**	**BLU**	**St. Ed's along creek**	**Eros capt**	**9.85**	**$ 351,806**	**28.00**
23.	14a.	BLU	St. Ed's along creek	Wet + BF + Eros	22.30	$ 829,027	26.89
24.	55d.	JOH	Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield	Wet + BF	22.53	$ 839,109	26.85
25.	97d.	WBO	South Center St. and Audrey Ct.	Wet + BF	21.60	$ 806,991	26.76
26.	25a.	BUL	Sierra Blanca & Centennial Trail	Wet + BF + Eros	17.89	$ 673,773	26.55
27.	27a.	BUL	W. of Old Lampasas Trail, N. of creek	Wet + BF + Eros	25.03	$ 973,838	25.70
28.	**95d.**	**WBO**	**Clawson & Rockdale**	**Wet + BF**	**7.90**	**$ 315,103**	**25.07**
29.	131f.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Irrig.	50.94	$ 2,031,922	25.07
30.	55c.	JOH	Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield	Wet + Eros	20.03	$ 830,361	24.12
31.	14d.	BLU	St. Ed's along creek	Wet + BF	15.43	$ 644,620	23.93
32.	55a.	JOH	Johnson Creek Greenbelt, along Winsted Ln., S. of Enfield	Wet + BF + Eros	19.66	$ 831,513	23.65
33.	**96d.**	**WBO**	**Bannister & Ben White**	**Wet + BF**	**10.11**	**$ 427,666**	**23.64**
34.	16b.	BLU	N. of Alpine	Eros capt	4.75	$ 202,834	23.43
35.	17c.	BLU	N. of Oltorf in Nature Pres.	Wet + Eros	16.94	$ 731,062	23.18
36.	**15a.**	**BLU**	**St. Ed's to Alpine**	**Wet + BF + Eros**	**20.37**	**$ 886,023**	**22.99**
37.	15d.	BLU	St. Ed's to Alpine	Wet + BF	14.91	$ 652,765	22.83
38.	**56e.**	**JOH**	**NE of L. Austin Blvd./MoPac/Cesar Chavez interchange**	**Wet pool**	**24.86**	**$ 1,093,260**	**22.74**
39.	**111b.**	**WAL**	**Walnut Creek Metro Park**	**Eros capt**	**65.80**	**$ 2,928,554**	**22.47**
40.	96a.	WBO	Bannister & Ben White	Wet + BF + Eros	12.77	$ 569,438	22.42

* Bolded facilities indicate the highest ranked configuration for a particular site; non-bolded facilities have a higher rated configuration also shown in this table.

Figure 5-1: Example Water Quality Feasibility Matrix Application for Capital Solutions

BMP Type	Erosion detention + Wet Pool with Baseflow augmentation	
Watershed	West Bouldin Creek	
WQ Reach ID	WBO3 / WBO845	
Cumul. Reach IC: current	54%	increase
Cumul. Reach IC: future	58%	+7%
Pct. Reach below BMP	50%	
Main Channel or Tributary	Main Channel	
	Present	Future
BMP DA/land acq'd (ac.)	1,050	
Imp. Cover (%)	50.0%	54.0%
Annual Q to BMP (%)	44.6%	44.6%
Capture Volume (in.)	0.66	
Total Volume (ac-ft)	26.54	
Irrigation Volume (ac-ft)	-	
Erosion Det. Vol. (ac-ft)	19.99	
Wet Pool Volume (ac-ft)	31.46	
Baseflow storage vol.	6.55	
Add'l Baseflow Yield (cfs)	0.15 cfs	
Capital Cost	$ 1,977,653	
O&M Cost/Year	$ 3,400	
Average Annual Cost	$ 175,800	
Current Narrative Rating	Poor	

BMP Categories	Watershed: Problem Score (Watershed totals) Total	Eligible	BMP Effect'ness Rating	Pct. Q in D.A. Treated	Impact Score	Pct. Total Possible Points
Current						
1a. TSS Load: Uplands	22.0	1.1	46.7%	44.6%	0.23	1.0%
1b. TSS Load: u.s. Chan.	"	7.9	46.7%	44.6%	1.65	7.5%
1c. TSS Load: d.s. Chan.	"	11.5	47.1%		5.43	24.7%
2. Nutrient Load	34.9	14.3	17.5%	44.6%	1.12	3.2%
3. Toxic Load	26.4	12.6	15.7%	44.6%	0.89	3.4%
4. Spills Risk	20.0	7.5	15.7%		1.18	5.9%
5. Baseflow Quantity	65.9	36.0	56.6%		20.36	30.9%
6. Physical Integrity	30.9	20.3	47.1%		9.55	30.9%
Present Subtotals	200.0	111.2			**40.40**	20.2%
Future						
1a. TSS Load: Uplands	1.2	0.1	46.7%	44.6%	0.01	0.9%
1b. TSS Load: u.s. Chan.	"	0.4	46.7%	44.6%	0.08	6.6%
1b. TSS Load: d.s. Chan.	"	0.7	42.3%		0.28	23.9%
2. Nutrient Load	1.0	0.4	17.5%	44.6%	0.03	2.8%
3. Toxic Load	2.8	1.0	15.7%	44.6%	0.07	2.5%
4. Spills Risk	6.7	2.7	15.7%		0.42	6.3%
5. Baseflow Quantity	9.7	6.0	55.0%		3.31	34.0%
6. Physical Integrity	1.6	0.9	42.3%		0.36	21.9%
Future Subtotals	23.1	12.0			**4.56**	19.7%
				WQ Score	**44.97**	20.2%

BMP Efficiency: TSS, Nutrients, Toxics/Spills	ac-ft capt.	TSS	DP	COD
Irrig	0.0	81%	81%	81%
Sed-Sand	0.0	68%	0%	52%
Eros (ED)	26.5	40%	0%	24%
Wet/Wetla	31.5	52%	32%	9%
	58.0	47%	18%	16%

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
REACH INFO		**DRAINAGE AREA CALCULATIONS**									**REACH LENGTH CALCS**				**RANK SCORE**		**Pct. of Problem**	
	Reach	Cumul.	Increm.	Area of Reach			Reach Area	Pct. of Reach		DA Capt	Reach	Length of Reach		Pct.	Rank Score		Pct. of Problem	
Reach	exists	Reach area	Reach area	u.s. BMP		d.s. BMP	+ u.s.	u.s. BMP	d.s. BMP	above BMP	length	u.s. BMP	d.s. BMP	d.s. BMP	Current	Future	Current	Future
1 WBO1	1.0	1,797	140	-		140	-	-	100.0%	58.4%	4,400	-	4,400	100.0%	76.0	5.6	93.1%	6.9%
2 WBO2	1.0	1,657	327	-		327	-	-	100.0%	63.4%	2,700	-	2,700	100.0%	0.4	5.7	6.6%	93.4%
3 WBO3	1.0	1,330	551	275		275	551	50.0%	50.0%	79.0%	3,100	1,550	1,550	50.0%	77.1	5.9	92.8%	7.2%
4 WBO4	1.0	779	779	779		-	779	100.0%	-	-	6,000	6,000	-	-	46.5	5.9	88.8%	11.2%
5 WBO5	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-
6 WBO6	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-
Totals		1,797	1,797	1,054		743	1,330	59%	41%	74%	16,200	7,550	8,650		200.0	23.1	89.7%	10.3%
												BMP reach						
											3,100	4,517	3,150					

REACH INF	**PHYSICAL INTEGRITY/CHANNEL DATA**												Reach Specific calcs		
	Channel	Channel	ERult/	Design storm		Future storms		Design storm vol.		Pct. design storm capt'd		Length of	Pct. design storm capt'd	
Reach	Type (raw)	Type (round)	ERcur	(time interval)		6-mo.	2-yr	current	future	current	future	d.s. BMP	current	future
1 WBO1	0.00	0.00	1.01	6-month	1	66.8	146.9	59.1	66.8	43.5%	38.5%	-	-	-
2 WBO2	0.00	0.00	1.05	6-month	1	61.6	135.4	54.5	61.6	47.2%	41.7%	-	-	-
3 WBO3	0.00	0.00	1.07	6-month	1	49.4	108.7	45.2	49.4	56.9%	52.0%	1,550	56.9%	52.0%
4 WBO4	0.00	0.00	1.10	6-month	1	29.7	65.4	26.5	29.7	97.1%	86.4%	-	97.1%	86.4%
5 WBO5	-	-	-	none	0	-	-	-	-	-	-	-	-	-
6 WBO6	-	-	-	none	0	-	-	-	-	-	-	-	-	-
Totals	0=AL (alluvial) or RB (rock-bottom); 1=RC (rock-controlled)/SC (structurally-controlled)									**47.1%**	**42.3%**	1,550	**56.9%**	**52.0%**
										Weighted Chan. Rating		Weighted Chan. Rating: Reach		

Figure 5-1: Example Water Quality Feasibility Matrix Application for Capital Solutions

REACH INF	BASEFLOW CALCS											1	2	3
	Baseflow		cfs/acre		Baseflow w BMP*				cfs/acre*		Baseflow		Pct. toward goal	
Reach	cfs cur	cfs fut	Present	Future	cfs added	cfs/ac added	cfs cur	cfs fut	Present	Future	Goal	Reach	Present	Future
1 WBO1	0.15	0.11	0.00008	0.00006	0.151	0.00008	0.30	0.26	0.00017	0.00015	0.00020	WBO1	72.0%	60.4%
2 WBO2	0.14	0.11	0.00008	0.00007	0.151	0.00009	0.29	0.26	0.00018	0.00016	0.00020	WBO2	78.8%	68.1%
3 WBO3	0.11	0.08	0.00008	0.00006	0.075	0.00006	0.19	0.16	0.00014	0.00012	0.00020	WBO3	24.2%	20.3%
4 WBO4	0.06	0.04	0.00008	0.00005	-	-	0.06	0.04	0.00008	0.00005	0.00020	WBO4	-	-
5 WBO5	-	-	-	-	-	-	-	-	-	-	-	WBO5	-	-
6 WBO6	-	-	-	-	-	-	-	-	-	-	-	WBO6	-	-
	0.107	0.078	0.000	0.000	0.080	0.00005	0.188	0.159	0.000	0.000	0.000	weighted	56.6%	55.0%
							Goal =	0.0002 cfs/acre [or existing cfs, if higher]				100.0% = max % toward goal		
	*weighted by position (e.g., 100% quantity increased x 20% reach affected = 20% toward goal)													

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

REACH INF	CURRENT PROBLEM SCORES															
	TSS: Uplands		TSS: u.s. Chan.		TSS: d.s. Chan.		Nutrient Load		Toxic Load		Spills Risk		Baseflow Quantity		Physical Integrity	
Reach	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*
1 WBO1	0.94	-	8.05	-	8.05	8.05	11.39	-	9.12	-	7.60	4.44	24.27	24.27	14.67	14.67
2 WBO2	0.01	-	0.04	-	0.04	0.04	0.03	-	0.06	-	0.04	0.03	0.13	0.13	0.09	0.09
3 WBO3	0.92	0.46	6.86	3.43	6.86	3.43	18.34	9.17	9.15	4.57	7.71	3.04	23.11	11.55	10.99	5.49
4 WBO4	0.65	0.65	4.50	4.50	4.50	-	5.15	5.15	8.04	8.04	4.65	-	18.34	-	5.15	-
5 WBO5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 WBO6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals	2.52	1.11	19.46	7.93	19.46	11.52	34.90	14.32	26.37	12.62	20.00	7.51	65.85	35.95	30.90	20.25
		44.0%		40.8%		59.2%		41.0%		47.9%		37.6%		54.6%		65.6%
Pct. Prob		90.5%		90.5%		92.7%		91.4%		90.3%		92.7%		92.7%		92.6%
	*eligible accounts for main chan v. trib, position of BMP u.s. or d.s. of PROBLEM, etc.															

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

REACH INF	FUTURE PROBLEM SCORES															
	TSS: Uplands		TSS: u.s. Chan.		TSS: d.s. Chan.		Nutrient Load		Toxic Load		Spills Risk		Baseflow Quantity		Physical Integrity	
Reach	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*	Raw	Eligible*
1 WBO1	0.03	-	0.26	-	0.26	0.26	0.26	-	0.71	-	1.62	0.95	2.35	2.35	0.41	0.41
2 WBO2	0.04	-	0.27	-	0.27	0.27	0.27	-	0.74	-	1.67	1.06	2.40	2.40	0.27	0.27
3 WBO3	0.04	0.02	0.28	0.14	0.28	0.14	0.28	0.14	0.77	0.38	1.70	0.67	2.53	1.26	0.35	0.18
4 WBO4	0.03	0.03	0.23	0.23	0.23	-	0.23	0.23	0.60	0.60	1.68	-	2.46	-	0.62	-
5 WBO5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6 WBO6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals	0.14	0.05	1.04	0.38	1.04	0.67	1.04	0.38	2.82	0.99	6.68	2.68	9.74	6.01	1.65	0.85
		37.6%		35.9%		64.1%		35.9%		35.0%		40.1%		61.8%		51.8%
Pct. Prob		9.8%		9.7%		41.4%		9.7%		9.6%		41.1%		41.5%		34.3%
	*eligible accounts for main chan v. trib, position of BMP u.s. or d.s. of problem, etc.															

5.1.2 Flood Control Feasibility Matrix for Creek and Storm Sewer CIP Solutions

Separate Feasibility Matrices were developed for: (1) creek flooding solutions; and (2) storm sewer flooding solutions.

Feasibility Matrix for CIP Flood Solutions on Creeks

Flood control projects were identified for the sixteen (16) top-rated flood problem areas. For each of these 16 creek flood control solutions, a normalized effectiveness score was developed and was provided to the Summary Matrix. The individual creek flood project effectiveness scores (specified on a scale of 0-100) were developed from normalized benefit values derived for each CIP creek flood solution. For each CIP creek flood solution, the flood project benefit is measured in units of combined flood reach Problem Score reduction.

Flood reach Problem Score reductions were determined as follows:

1. The top 16 flood control projects were selected, preliminarily designed, and the hydraulic impacts modeled with HEC-RAS or estimated as described in the initial solutions identification protocol.
2. Based upon this information for each project, reduced flood elevations were input to the City's ArcView-based software which translates HEC-RAS flood data into spatially distributed depths at individual structures in the ArcView GIS system.
3. Output from the City's Arc-View program was processed through the ArcView-based software developed by CDM which calculates accumulated property protection and public safety Problem Scores for individual structures based upon the flood depths at each structure provided by the City software.
4. The differences in the flood Problem Scores with and without the prospective flood project represents the benefit assigned to the project in units of flood Problem Score.

Flood project costs were estimated using spreadsheet-based costing functions with unit prices derived from recent contractor's bid data. For projects developed by other entities, prices were defined through adjustment of price estimates provided from the other studies. Flood project cost was estimated as the present value of the initial project capital cost and the expected ongoing operations and maintenance costs.

Table 5-3 presents a summary of the top 16 flood control capital projects including normalized flood control scores, costs, and cost-effectiveness calculations for all of the capital solutions evaluated for creek flood problems. These normalized scores are those included in the Summary Matrix.

The flood problems assessment process identified approximately 300 flood reaches with flooding problems. The top 16 projects described in Table 5-3 solve problems in approximately 45 reaches (15% of the 300 total). However, these projects account for 73% (917 of 1260) of the total flood areas problem score.

In order to estimate costs for the 150-200 flood projects that can be developed to address the remaining 27% of the citywide flood problem score, a function was developed comparing

Table 5-3: Summary of Top Rated Flood Problem Areas with Capitol Solutions

Project Number	Water-shed	Trib 1	Trib 2	Station		Project Scores and Benfits						Buyout			Solution Type	Project Area
				From	To	Public Safety	Property Protection	Norm. Score	Norm. Benefit	Cost ($M)	Benefit Cost ($M)	Benefit	Cost ($M)	Benefit Cost ($M)		
1	WLN*	000	000	180+00	216+00	65,672	13,471	273.83	273.83	0.455	601.87				Buyout	Austin Hills Mobile Home Estates
2	WLN	000	000	222+25	379+45	33,191	6,052	150.04	150.04	4.600	32.62	150.04	27.55	5.45	Channelization, Flood Wall	Crystal Brook
3	SHL	000	000	00+00	83+05	9,403	3,433	67.96	67.96	30.000	2.27	67.96	34.66	1.96	Tunnel	19th St Tunnel
4a	LWA	000	000	360+40	440+70	16,154	2,239	63.15	63.15	5.328	11.85	63.15	38.99	1.62	Storm Drain, Channelization	Mearns Meadow Blvd
4b	LWA	000	000	360+40	440+70	16,154	2,239	63.15	63.15	2.541	24.85				Concrete Lined Channel	Mearns Meadow Blvd
5	WLN*	000	000	216+00	244+00	15,577	1,550	59.26	59.26	1.756	33.75				Buyout	Pecan Mobile Home Park
6	FOR	000	000	47+13	100+40	10,608	1,907	47.93	46.61	1.861	25.05	48.00	4.04	11.88	Channelization, Struct Repl	Eleanor Dr
7	WMS	000	000	00+00	562+10	17,219	2,605	70.13	30.31	2.847	10.65	71.00	76.88	0.92	Detention	Sunset Valley (Kincheon Br and Main Stem)
8a	BUL	000	000	40+60	103+50	7,678	900	27.73	27.73	6.166	4.50	4.70	4.50	1.04	Structure Repl, Buyout	RM 2222 and Lakewood Dr
8b	BUL	000	000	40+60	103+50	7,678	900	27.73	23.03	1.666	13.83				Structure Repl	RM 2222 and Lakewood Dr
9	BOG	000	000	283+60	320+00	4,233	928	21.32	21.32	3.967	5.37	21.32	3.97	5.37	Buyout	Banton Rd
10	BUL	000	000	263+50	320+50	4,296	606	27.66	18.19	1.805	10.08				Structure Repl	Spicewood Springs Rd (upstr sta 263+50)
11	WMS	SNV	000	00+00	22+60	2,633	722	15.28	15.28	2.304	6.63				Storm Drain	Ektom Dr and Tahoe Tr
12a	WMS	000	000	460+90	502+50	3,240	574	14.41	14.41	11.888	1.21				Channelization (wo Reg. Det.)	Buckskin Pass
12b	WMS	000	000	460+90	502+50	1,408	258	6.39	6.39	10.816	0.59				Channelization (w Reg. Det.)	Buckskin Pass
13	WBO*	000	000	216+00	244+00	1,833	371	7.64	7.64	0.825	9.26				Buyout	Woodview Mobile Home Park
14	BUL	000	000	242+70	263+50	1,810	267	7.30	7.30	0.698	10.46				Structure Repl	Spicewood Springs Rd (sta 250+00)

Table 5-3: Summary of Top Rated Flood Problem Areas with Capitol Solutions

Project Number	Water-shed	Trib 1	Trib 2	Station		Project Scores and Benfits						Buyout			Solution Type	Project Area
				From	To	Public Safety	Property Protection	Norm. Score	Norm. Benefit	Cost ($M)	Benefit Cost ($M)	Benefit	Cost ($M)	Benefit Cost ($M)		
15a	WMS	000	000	521+50	541+60	3,068	568	13.95	7.00	2.079	3.37				Buyout, Floodwall (wo Reg. Det.)	Bayton Lp
15b	WMS	000	000	521+50	541+60	2,551	480	11.74	5.94	2.079	2.86				Buyout, Floodwall (w Reg. Det.)	Bayton Lp
16a	BUL*	000	000	105+00	105+00	938	70	4.49	4.06	0.622	6.53				Structure Repl	Lakewood Dr
16b	WMS	000	000	323+60	342+10	216	83	1.59	1.46	0.150	9.72				Structure Repl	Wasson Rd
16c	WMS*	000	000	785+75	785+75	293	34	1.43	1.30	0.327	3.98				Structure Repl	Old Bee Caves Rd
16d	WMS*	000	000	739+15	739+15	264	29	1.29	1.13	0.386	2.94				Structure Repl	Joe Tanner Ln
16e	WLN	T09	000	60+10	79+90	101	18	0.45	0.40	0.344	1.16				Structure Repl (bridge)	McNeil Rd
16f	WLN	T09	000	60+10	79+90	101	18	0.45	0.39	0.150	2.59				Structure Repl (culvert)	McNeil Rd
Extra**	WMS	CCK	000	19+82	60+41	451	51	1.60	1.15	1.097	1.05	1.60	5.78	0.28	Detention	William Cannon & Cherry Cr (Aldford to Coatbridge)
Extra**	TAN	000	000	01+00	121+80	680	142	3.33				3.33	0.77	4.35	Buyout	Wildrose Dr & Temple Dr
Extra**	LWA	000	000	20+40	42+80	512	66	1.93				1.93	0.35	5.48	Buyout	Waynesburg Cv
Extra**	WMS	000	000	681+50	700+70	287	42	1.15				1.15	2.25	0.51	Buyout	Fair Valley Tr
Extra**	LWA	000	000	00+00	20+40	224	28	0.83				0.83	0.23	3.65	Buyout	Little Walnut Pkwy
Extra**	LWA	000	000	00+00	20+40	224	28	0.83				0.83	0.23	3.65	Buyout	Little Walnut Pkwy
Extra**	WMS	000	000	659+00	681+50	237	23	0.79				0.79	2.57	0.31	Buyout	Yellow Rose Tr
Extra**	WBO	000	000	158+80	175+16	184	30	0.78				0.78	2.72	0.29	Buyout	Valleyridge Cir
Extra**	LWA	000	000	440+70	472+10	80	22	0.47				0.47	16.33	0.03	Buyout	Little Pebble Dr
Extra**	SHL	HAN	000	21+30	43+20	54	20	0.39				0.39	3.98	0.10	Buyout	Hancock Dr & Burnet Rd

* This structure data was not included in flood reach data

** The extra problem area calculations were included to determine benefit-cost and buyout trends

917.28	Total Flood Benefit for Evaluated Projects
1,260.48	Total Flood Problem Score
73%	Flood Problem Solved by Top Rated Projects

project benefit to project benefit/cost. This allows for estimation of project cost for any identified project with assigned flood problem score (benefit). The benefit vs. benefit/cost curves were plotted using the 16 high-rated projects and approximately 10 additional "extra" projects from a range of lower-rated flood problem areas preliminarily evaluated by Loomis & Moore. Figure 5-2 presents plots of the flood projects benefit vs. benefit/cost functions. Appendix B-4 presents approximate flood remediation costs for all problem reaches.

Storm Sewer Feasibility Matrix for CIP Flood Solutions

For each prospective storm sewer project site, normalized flood control effectiveness scores based upon project benefit and project benefit/cost were provided to the Summary Matrix. The individual storm sewer project flood control effectiveness scores were developed from the composited (public safety and property protection) flood Problem Scores (FC) derived for each storm sewer CIP solution. For storm sewer projects, project implementation is assumed to eliminate the local problem, thus benefits are measured in flood Problem Score points and are equal to the total Problem Score. For the normalization procedure, FC values for storm sewers were integrated with FC values for creek flood solutions to allow for direct comparison of creek vs. storm sewer projects.

Flood Problem Score reductions were developed as follows for the 17 prospective storm sewer CIP project sites:

1. A flood problem scoring system was developed for storm sewer projects comparable to the system developed for creek flood problems to calculate "master reach scores." The system for storm sewer problems maintains the basic form of the master reach score equation:

   $$FC = [[S_{fps}/(S_{fps}+S_{fpp})]*FC_{ps}] + [[S_{fps}/(S_{fps}+S_{fpp})]*FC_{pp}]$$

2. For storm sewer problems, FC_{ps} and FC_{pp} are calculated in a manner similar to that used for creek flooding where:

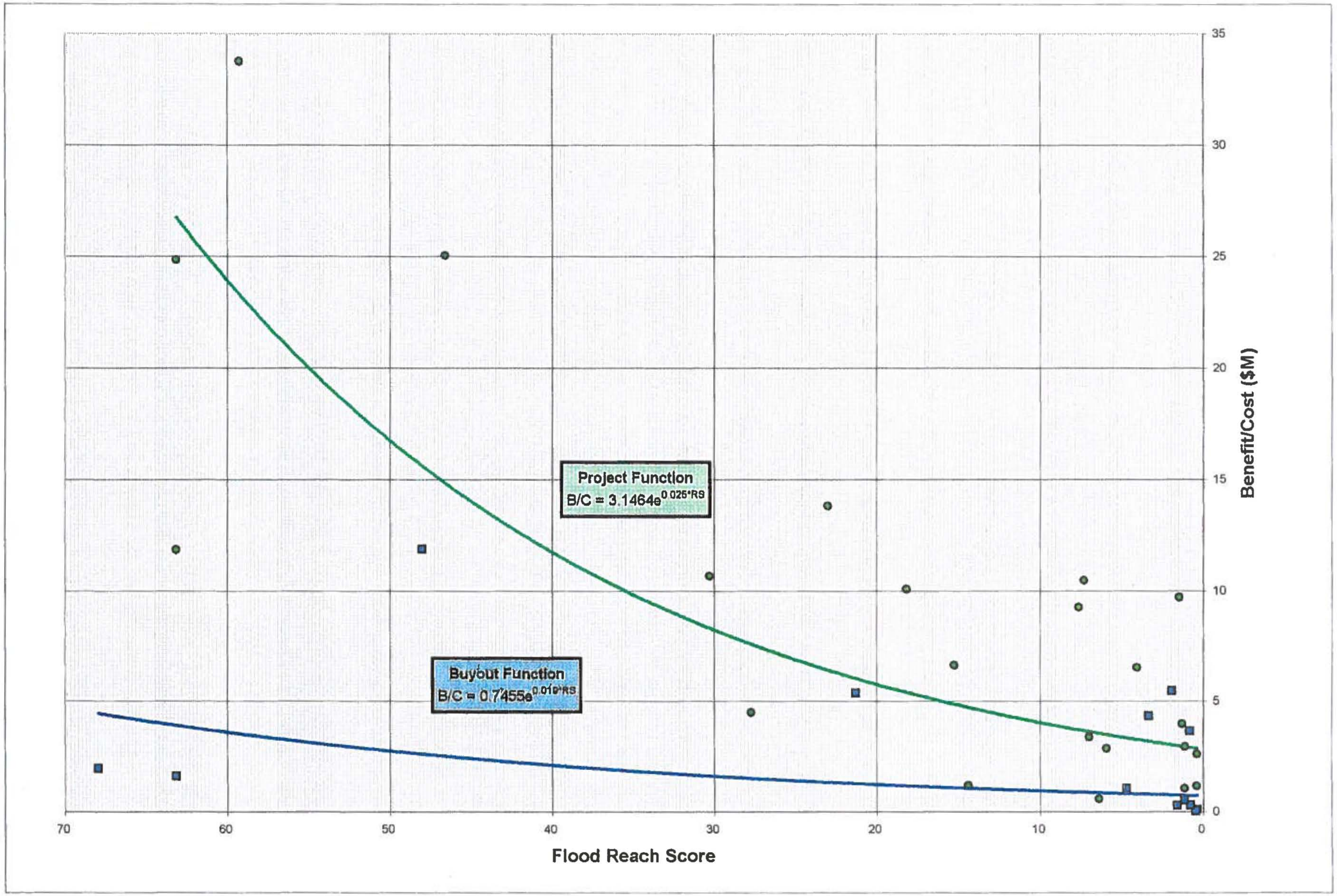
   $$FC_{pp} = ½(D_2)RV + 1/10(D_{10})RV + 1/25(D_{25})RV + 1/100(D_{100})RV; \text{ and}$$

   $$FC_{ps} = ½(D_2)(V_2)RV + 1/10(D_{10})(V_{10})RV + 1/25(D_{25})(V_{25})RV + 1/100(D_{100})(V_{100})RV$$

   These formulations of the original equation assume that flood velocities and depths for the 10-, 25-, and 100-year floods will not increase substantially in an urban storm sewer context above the value for the 2-year event. Flow velocity in a storm sewer setting was assumed to be a constant value of 5 fps for all recurrence intervals. Flow depth in a storm sewer setting was assumed to be a constant value of 1 foot for all recurrence intervals.

3. Resource values for the storm sewer problem areas were assumed to be the same as for creek flooding. To balance the fact that few structures are flooded with the storm sewer problems, two additional resource value parameters—"number of city blocks impacted" and "threat of pipe collapse"—were added for the storm sewers analysis. Resource values assigned to impacted urban and suburban storm sewer problem elements are as follows:

Figure 5-2: Project Benefit-Cost vs. Benefit for Capital Projects and Buyouts



Public Safety Resource Values	
Downtown Block Impacted	100
Dense Urban Block Impacted	80
Suburban Block Impacted	20
Residential Block Impacted	10
High Collapse Risk/Block	20
Medium Collapse Risk/Block	10
Low Collapse Risk/Block	0
Residential Structure	80
Non-Residential Structure	40

Property Protection Resource Values	
Downtown Block Impacted	50
Dense Urban Block Impacted	40
Suburban Block Impacted	10
Residential Block Impacted	5
High Collapse Risk/Block	10
Medium Collapse Risk/Block	5
Low Collapse Risk/Block	0
Residential Structure	40
Non-Residential Structure	80

4. For all storm sewer flood problem sites, it was assumed that storm sewer upgrades will eliminate all flood and public safety problems for the design flood. Thus, the benefit associated with implementation of a particular storm sewer project was calculated as the Problem Score for the corresponding problem area.

For each storm sewer problem area, the Stormwater Management Division provided the project team with a listing of required pipe improvement lengths, required pipe size, the number of additional inlets to be constructed, along with other site-specific information which was used to develop project cost estimates. Storm sewer flood project costs were estimated using spreadsheet-based costing functions with unit prices derived from recent contractor's bid data. Table 5-4 presents project descriptions and cost analyses for the 17 storm sewer sites. Unit cost values assume storm sewer replacement construction in highly urbanized settings with substantial traffic, congestion, and probable utilities conflicts.

Table 5-5 presents a summary of benefits calculations, benefit values, and cost-benefit values for the top 17 capital storm sewer projects. Appendix B-2 presents project descriptions and flood benefit summaries for top-rated flood projects. Appendix B-3 presents a summary of all flood problem area scores with identification of top-rated capital solutions. Appendix B-4 presents approximate costs for all flood solutions.

5.1.3 Erosion Control Feasibility Matrix for Capital Solutions

Two categories of capital solutions were considered for solving erosion problems: (1) side slope treatments and (2) stormwater detention. These two solution methods control erosion in different ways requiring separate Feasibility Matrices for their evaluation. Side slope treatment projects provide erosion control in the immediate vicinity in which they are constructed; they can solve existing erosion threats, such as the undercutting of a house along a channel bank. Side slope protection may not be able to provide long-term protection for banks in areas with rapidly developing watersheds.

Detention ponds capture storm flows and reduce erosive flow rates across multiple stream reaches. Ponds can also help compensate for the effects of future development if designed to capture future conditions erosive flow events. However, ponds do not provide relief for currently threatened structures and other features.

Table 5-4: Storm Sewer Projects Descriptions and Costs Analyses

Problem Area	Facility Problem	Pipe Size Needed	Pipe Unit Cost	System Length	No. of Inlets Needed	Cost					
						Inlets ($4K each)	Storm Sewer Pipe	Road Repair	Engin. (8-12%)	20% Contin-gency	Estimated Total Cost
1.0 Colorado Street	Inadequate storm sewer at Intersections. Street reconstruction project imminent	18 in.	$60/lf	1930	48	$ 192,000	$ 115,800	$ 64,333	$ 43,652	$ 83,157	$ 498,942
2.0 Pleasant Valley at Elmont	Major arterial flooding.	24 in.	$70/lf	150	2	$ 8,000	$ 10,500	$ 6,667	$ 5,000	$ 6,033	$ 36,200
3.0 San Antonio from Nueces @ 16th, up S.A. to MLK	Inadequate, unreinforced storm sewer system. Currently 8x8 Arch	72 in.	$400/lf	1400	18	$ 72,000	$ 560,000	$ 186,667	$ 93,189	$ 182,371	$ 1,094,226
4.0 San Antonio/Guadalupe alley from MLK north to 23rd	Inadequate 42" RCP	54 in.	$300/lf	1650	16	$ 64,000	$ 495,000	$ 165,000	$ 82,946	$ 161,389	$ 968,335
5.0 Nueces Street (L. Shl Crk. Tunnel)	Old stone arch. Building encroachments.	10x10 plus	$700/lf	4650	48	$ 192,000	$ 3,255,000	$ 1,722,222	$ 413,538	$ 1,116,552	$ 6,699,312
6.0 E. 16th bet. San Antonio and Guadalupe	Collapsed line.	24 in.	$70/lf	420	11	$ 44,000	$ 29,400	$ 18,667	$ 11,000	$ 20,613	$ 123,680
7.0 Lavaca Street (f.TWN, up 1st, up Lav. To 8th)	Inadequate storm sewer system.	48 in.	$200/lf	2400	30	$ 120,000	$ 480,000	$ 213,333	$ 92,615	$ 181,190	$ 1,087,138
8.0 12th at Lamar	Deteriorating storm sewer	42 in.	$175/lf	800	8	$ 32,000	$ 140,000	$ 62,222	$ 27,726	$ 52,390	$ 314,338
9.0 15th St SS (Shoal & Waller watersheds)	Road reconstruction project	36 in.	$120/lf	800	12	$ 48,000	$ 96,000	$ 53,333	$ 23,416	$ 44,150	$ 264,899
10.0 E. 7th, from Concho to Comal SS system	Old deteriorating lines (un-reinforced C.P.)	48 in.	$200/lf	350	8	$ 32,000	$ 70,000	$ 31,111	$ 15,862	$ 29,795	$ 178,767
11.0 East 9th St. (Brazos - Congress) SS	Bad condition	30 in.	$100/lf	500	10	$ 40,000	$ 50,000	$ 27,778	$ 14,049	$ 26,365	$ 158,192
12.0 Garden Villa	Needs inlet and storm sewer system.	24 in.	$70/lf	400	2	$ 8,000	$ 28,000	$ 17,778	$ 6,441	$ 12,044	$ 72,263
13.0 Rutherford @ Grayledge	Needs SS system to replace borrow ditch	24 in.	$70/lf	150	2	$ 8,000	$ 10,500	$ 6,667	$ 5,000	$ 6,033	$ 36,200
14.0 All SS E. 3rd (Chalmers to R.T.M. to Pedernales)	Old deteriorating lines (un-reinforced C.P.)	48 in.	$200/lf	2200	15	$ 60,000	$ 440,000	$ 195,556	$ 79,841	$ 155,079	$ 930,476
15.0 E. 3rd (R.T.M. to Pedernales)	Collapse at Zavala already	72 in.	$400/lf	1400	12	$ 48,000	$ 560,000	$ 186,667	$ 90,605	$ 177,054	$ 1,062,326
16.0 Rio Grande (5-A-75 SS), MLK-26		36 in.	$120/lf	1300	12	$ 48,000	$ 156,000	$ 86,667	$ 34,280	$ 64,989	$ 389,936
17.0 3910 Ridgelea to Idlewild	Pipe in ditch. Erosion. Pipe under house	42 in.	$175/lf	380	4	$ 16,000	$ 66,500	$ 29,556	$ 13,371	$ 25,085	$ 150,512

Table 5-5: Summary of Benefits Calculations, Benefit Values, and Cost-Benefit Values for the Top 17 Capital Storm Sewer Projects

Problem Area	System Length	Structures				City Blocks (CB)				Collapse			PS Score	PP Score	Estimated Project Cost	Flood Score	Flood Score Reduction Cost - $M
		No.	Type*	RV** PS	RV** PP	Impacted	Type	RV** PS	RV** PP	Risk	RV (per CB) PS	RV (per CB) PP					
1.0 Colorado Street	1,930	0	Non-Resid	40	80	6	Downtown	100	50	Low	0.00	0.00	1950	390	$ 498,942	8.10	16.23
2.0 Pleasant Valley at Elmont	150	0	Non-Resid	40	80	1	Suburban City	20	10	Low	0.00	0.00	65	13	$ 36,200	0.27	7.46
3.0 San Antonio from Nueces @ 16th, up S.A. to MLK	1,400	0	Non-Resid	40	80	4	Dense Urban	80	40	High	20.00	10.00	1120	248	$ 1,094,226	4.73	4.33
4.0 San Antonio/Guadalupe alley from MLK north to 23rd	1,650	1	Non-Resid	40	80	2	Dense Urban	80	40	Low	0.00	0.00	585	117	$ 968,335	2.43	2.51
5.0 Nueces Street (L. Shl Crk. Tunnel)	4,650	0	SFR	60	40	5	Residential	10	5	Medium	10.00	5.00	212.5	57.5	$ 6,699,312	0.93	0.14
6.0 E. 16th bet. San Antonio and Guadalupe	420	0	Misc.	10	10	2	Dense Urban	80	40	High	20.00	10.00	560	124	$ 123,680	2.37	19.14
7.0 Lavaca Street (f.TWN, up 1st, up Lav. To 8th)	2,400	0	Non-Resid	40	80	4	Downtown	100	50	Medium	10.00	5.00	1340	280	$ 1,087,138	5.61	5.16
8.0 12th at Lamar	800	12	Non-Resid	40	80	4	Dense Urban	80	40	High	20.00	10.00	1900	404	$ 314,338	7.97	25.36
9.0 15th St SS (Shoal & Waller watersheds)	800	0	Non-Resid	40	80	2	Dense Urban	80	40	Medium	10.00	5.00	540	114	$ 264,899	2.26	8.54
10.0 E. 7th, from Concho to Comal SS system	350	0	SFR	60	40	3	Residential	10	5	High	20.00	10.00	157.5	49.5	$ 178,767	0.72	4.01
11.0 East 9th St. (Brazos - Congress) SS	500	0	Non-Resid	40	80	2	Downtown	100	50	Medium	10.00	5.00	670	140	$ 158,192	2.80	17.72
12.0 Garden Villa	400	1	MFR	80	60	1	Residential	10	5	Low	0.00	0.00	162.5	32.5	$ 72,263	0.67	9.34
13.0 Rutherford @ Grayledge	150	1	SFR	60	40	1	Residential	10	5	Low	0.00	0.00	130	26	$ 36,200	0.54	14.91
14.0 All SS E. 3rd (Chalmers to R.T.M. to Pedernales)	2,200	0	SFR	60	40	7	Residential	10	5	High	20.00	10.00	367.5	115.5	$ 930,476	1.67	1.80
15.0 E. 3rd (R.T.M. to Pedernales)	1,400	1	MFR	80	60	4	Residential	10	5	High	20.00	10.00	340	92	$ 1,062,326	1.49	1.41
16.0 Rio Grande (5-A-75 SS), MLK-26	1,300	0	Non-Resid	40	80	1	Suburban City	10	5	Low	0.00	0.00	32.5	6.5	$ 389,936	0.13	0.35
17.0 3910 Ridgelea to Idlewild	380	4	SFR	60	40	3	Residential	10	5	Low	0.00	0.00	487.5	97.5	$ 150,512	2.02	13.45

* SFR = Single Family Residential; MFR = Multifamily Residential; Non-Resid. = Non-Residential

** RV = Resource Value; PS = Public Safety; PP = Property Protection

Land Use	(RV_{ps})	(RV_{pp})
Public Care Facilities	100	100
Non-Residential	40	80
Residential, Multi-Family	80	60
Residential, Single Family	60	40
Miscellaneous	10	10
Unclassified	0	0

Land Use	(RV_{ps})	(RV_{pp})
Downtown City Blocks	100	50
Dense Urban City Blocks	80	40
Suburban City Blocks	20	10
Residential Blocks	10	5
High Collapse Risk (per City Block)	20.00	10.00
Mediunm Collapse Risk (per City Block)	10.00	5.00
Low Collapse Risk (per City Block)	0.00	0.00

Flood Score Normalization Factor
(based on Crystal Brook Flooding Reach)
0.00692

The two erosion control CIP Feasibility Matrices were used to develop effectiveness scores input to the Summary Matrix for each erosion control solution. These scores were normalized to a 0-100 point scale to allow direct comparison between side slope treatments and stormwater detention projects.

Problem Score Points as Unit of Measure for Reaches and Watersheds

The Erosion Control Feasibility Matrices derived quantitative benefit values for each specific, prospective capital project. Benefits were measured in units of "Problem Score" points. The Problem Scores were based upon the findings presented in the *Watershed Erosion Assessments* (Chan & Associates, 1998); in these documents, detailed assessments were made of each of the study area's 199 geomorphic erosion reaches. The Problem Score values reflect the degree of erosion concern in each reach. The Problem Scores themselves were composed of six factors chosen to collectively define a watershed's condition with respect to erosion:

	Maximum Points in Total Score	
Factor	**Side Slope Projects**	**Pond Projects**
1. No. of Type 1 Problems	30	0
2. No. of Type 2 Problems	20	.0
3. Type 3 Problem Score*	15	15 x no. of reaches affected
4. Enlargement Ratio	15	15 x no. of reaches affected
5. Sediment Yield	15	15 x no. of reaches affected
6. Grade Control (Knick Points)	5	0
Totals	100	45 x no. of reaches affected

*Original score from the *Watershed Erosion Assessments* (Chan & Associates, 1998); score includes a weighted consideration of structures, fences, trees, etc. threatended on private property, plus public parklands and trails.

The Side Slope Treatment Erosion Control Feasibility Matrix ("Side Slope EC Matrix") used scores for erosion control project reaches which were defined in a different manner from the original geomorphic erosion reaches. Only the portion of a geomorphic reach which was threatened by erosion would need attention; some side slope project reaches also spanned between geomorphic reaches. The Detention Pond Erosion Control Feasibility Matrix ("Detention EC Matrix") used the original geomorphic erosion reach designations since the nature of detention ponds is to affect all flows for all reaches below the structure.

Side Slope Treatment Feasibility Matrix for Erosion Solutions

The Side Slope EC Matrix assumes that each project completely repairs all problems in the project reach. Therefore, points for all of the six factors cited above would be fully credited. For example, any Type 1 problems (threatened homes, etc.) are considered to be corrected and any sediment yield prior to the project from the area is assumed to be reduced to zero.

The Side Slope EC Matrix estimates costs for each project based upon the amount of side slope coverage to be implemented using cost data from recent construction bid estimates. Due to highly site specific considerations in selecting proper erosion slope treatments, a single generic costing function was utilized for side slope treatment solutions.

Table 5-6 presents the top [40] most effective side slope erosion control capital solutions. Table 5-7 presents the top [40] most *cost*-effective side slope erosion control capital solutions. Appendix C-3 presents a complete listing of the scores, costs, and cost-effectiveness calculations for all 93 side slope erosion solutions evaluated. These normalized scores are those included in the Summary Matrix. Some of the projects can be combined together to form larger, single projects, but they were left unaggregated in the analysis so that the units of measure (project size, measured in length) would be relatively uniform.

The details of how each project would be designed were not attempted; each solution will require a site-specific evaluation of the geomorphic and hydrologic conditions which will control a final design. Of the many different types of side slope treatment methods discussed in the Inventory, many projects will require more than one in order to stabilize a given area. For example, a single project might require gabions on an outside bend due to high velocity flows and a bioengineered solution with a reinforced toe on the inside bend where velocities are less destructive.

Stormwater Detention Ponds Feasibility Matrix for Erosion Solutions

In the Detention EC Matrix, the amount of benefit (Problem Score reduction) provided was calculated by estimating the portion of the channel-forming design storm captured for each geomorphic erosion reach influenced by the pond. The size of the storm required to be captured in each erosion reach was calculated using the method presented in Section 5.1.1.2 above for downstream problem control. The percent effectiveness of a particular CIP erosion pond is assumed to vary linearly from zero (no capture) to 100 percent (full capture of the required storm runoff volume). Multiple reaches below a pond can benefit, thus the scores reflect the collective impact of the erosion detention ponds on the watershed as a whole. Reaches located upstream of the erosion facility can receive no benefit. Figure 5-3 presents an example of Detention EC Matrix application for erosion pond CIP solutions.

Table 5-8 presents the top [40] most effective pond erosion control capital solutions. Table 5-9 presents the top [40] most *cost*-effective pond erosion control capital solutions. Appendix C-4 presents a complete listing of the scores, costs, and cost-effectiveness calculations for all stormwater detention erosion solutions evaluated.

5.1.4 Feasibility Matrix for Land and Conservation Easement Acquisition

The Land and Conservation Easement Acquisition Feasibility Matrix ("Land Matrix") was developed by Loomis & Moore with consultation from Watershed Protection Department staff. This method was developed to provide an objective means for weighing the relative benefits of alternative land or conservation easement tract purchases. At the City's request, no analyses of specific tracts was presented in this report to avoid potentially negative impacts on land purchase negotiations.

Table 5-6: Top 40 Most Effective Side Slope Erosion Control Capital Solutions

Rank	Proj. No.	Wshed	Location	Erosion Score
1.	75.	WAL	I.H. 35 to 100' u/s of Lamar Blvd.	27.52
2.	72.	WAL	2300' d/s of Highway 290 to 2100' u/s of Highway 290	31.90
3.	73.	WAL	1250' d/s of Springdale Rd.	39.01
4.	80.	WLR	From 450' above mouth of Waller Creek to 200' u/s of E. 9th St.	9.48
5.	74.	WAL	4880' d/s of E. Dessau Rd. to 2220' u/s of E. Dessau Rd.	16.55
6.	77.	WAL	Tx. - New Orleans R.R. crossing to 500' u/s (Tributary No. 1)	4.27
7.	16.	BUL	1600' d/s to 950' d/s of North Creekwood Dr.	3.18
8.	66.	WBO	From 1000 feet d/s of Cumberland Road extended to Cumberland Road	3.00
9.	71.	WAL	2620' d/s of Manor Rd. to 800' u/s of Manor Rd.	34.08
10.	30.	EBO	Just u/s of Gillis Park to 100 ft d/s of Cumberland Road	5.92
11.	25.	CNT	New CC, from confluence with Colorado River to 600 ft u/s of confluence	8.99
12.	11.	BMK	From 30 ft u/s of Bennett Avenue to Chevy Chase Drive	8.29
13.	45.	LWA	1800' d/s of Hwy. 290 to 1300' u/s of Hwy. 183	4.06
14.	63.	TAN	From Andover Pl. to 600' d/s of Cameron Rd.	13.42
15.	52.	SHL	From W. 25th St. to W. 28 1/2 th St.	5.39
16.	76.	WAL	550' u/s of Water Park Rd. to 700' u/s of Duval Rd.	9.53
17.	37.	FOR	From 350' u/s o f Briarcliff Blvd. to U.S. Hwy 290.	1.69
18.	14.	BOG	From 300' d/s of E. 12th St. to E. 19th St.	8.67
19.	51.	SHL	From W. 15th St. to 400' d/s of Windsor Rd.	17.35
20.	27.	EBO	From 200 ft d/s of Riverside Dr. to 200 ft. d/s of Congress Avenue	10.28
21.	48.	LWA	Quail Creek Branch - 300' u/s of Colliefield Dr. to 500' u/s of Parkfield Dr.	2.88
22.	88.	WMS	1500' d/s of 1st St. to 700' u/s of Emerald Forest Dr.	10.55
23.	13.	BOG	From 150' d/s of E. 11th St. to 100' u/s of the Tx. New Orleans R.R.	16.17
24.	20.	BUL	2100' d/s of Rain Creek Pkwy. to just below Rain Creek Pkwy. (Tributary No. 2)	8.43
25.	64.	TAN	From 150' d/s of Bennett St. to Helen St.	1.53
26.	55.	SHL	From New Haven Ct. to Ricky Dr.	6.90
27.	18.	BUL	14,700' to 16,200' u/s of Spicewood Springs Rd. / Yucca Mountain Rd. intersection	3.41
28.	61.	TAN	From E. 19th St. to 1300' d/s of Manor Rd.	9.94
29.	32.	FOR	From 300' d/s of the Missouri-Kansas Railroad to 1800' u/s.	10.56
30.	33.	FOR	From Harold Ct. to Lott Ave.	9.54
31.	91.	WMS	Meadow Dr. to Silvermine Dr.	5.48
32.	24.	CNT	New CC, from Oltorf Street to 500 ft d/s of Burleson Road	20.35
33.	28.	EBO	From 600 ft u/s of S. 1st St. Crossing (1st) to 2300 ft u/s of S. 1st St. Crossing (1st)	6.61
34.	62.	TAN	From Manor Rd. to 300' d/s of Berkman Dr.	17.39
35.	41.	JOH	From 100' d/s of Griswold Ln. to 500' u/s.	3.90
36.	34.	FOR	From Delano St. to 200' d/s of Heflin Ln.	8.27
37.	78.	WAL	500' d/s of Cedar Bend Dr. to 3500' u/s of Parmer Ln. (Wells Branch)	32.61
38.	83.	WLR	From 200' u/s of W. 46th St. to 600' D/s of E. 51st St.	5.40
39.	57.	SHL	From Steck Ave. to 650' d/s of Cross Creek Dr.	1.83
40.	26.	CNT	New CC, from 100 ft d/s of Riverside Dr. Bridge to 50 ft u/s of Riverside Dr. Bridge	15.59

Table 5-7: Top 40 Most Cost-Effective Side Slope Erosion Control Capital Solutions

Rank	Proj. No.	Wshed	Location	Erosion Score	Capital Cost	Effect/Cost x 1,000,000
1.	22.	BUL	3400' u/s of confluence with Bull Creek main stem (Tributary No. 3)	1.78	$ 15,000	118.67
2.	87.	WMS	2000' d/s of I.H. 35 to 1000' u/s of I.H. 35	3.96	$ 1,050,000	3.77
3.	23.	BUL	600' d/s to 1300' u/s of Spicewood Springs Rd. (Tributary No. 4)	10.36	$ 380,000	27.26
4.	27.	EBO	From 200 ft d/s of Riverside Dr. to 200 ft. d/s of Congress Avenue	10.28	$ 560,000	18.35
5.	73.	WAL	1250' d/s of Springdale Rd.	39.01	$ 782,000	49.89
6.	72.	WAL	2300' d/s of Highway 290 to 2100' u/s of Highway 290	31.90	$ 423,000	75.40
7.	85.	WLR	From E. 26th St. to W. 30th St.	14.94	$ 775,000	19.28
8.	74.	WAL	4880' d/s of E. Dessau Rd. to 2220' u/s of E. Dessau Rd.	16.55	$ 1,775,000	9.32
9.	48.	LWA	Quail Creek Branch - 300' u/s of Colliefield Dr. to 500' u/s of Parkfield Dr.	2.88	$ 630,000	4.58
10.	71.	WAL	2620' d/s of Manor Rd. to 800' u/s of Manor Rd.	34.08	$ 370,000	92.10
11.	20.	BUL	2100' d/s of Rain Creek Pkwy. to just below Rain Creek Pkwy. (Tributary No. 2)	8.43	$ 420,000	20.07
12.	26.	CNT	New CC, from 100 ft d/s of Riverside Dr. Bridge to 50 ft u/s of Riverside Dr. Bridge	15.59	$ 165,000	94.51
13.	75.	WAL	I.H. 35 to 100' u/s of Lamar Blvd.	27.52	$ 1,425,000	19.31
14.	66.	WBO	From 1000 feet d/s of Cumberland Road extended to Cumberland Road	3.00	$ 350,000	8.58
15.	61.	TAN	From E. 19th St. to 1300' d/s of Manor Rd.	9.94	$ 875,000	11.36
16.	37.	FOR	From 350' u/s o f Briarcliff Blvd. to U.S. Hwy 290.	1.69	$ 595,000	2.85
17.	24.	CNT	New CC, from Oltorf Street to 500 ft d/s of Burleson Road	20.35	$ 1,050,000	19.38
18.	79.	WAL	400' u/s of Parmer Ln. to 1200' u/s of Oak Creek Dr. (Tributary No. 9)	8.99	$ 710,000	12.66
19.	63.	TAN	From Andover Pl. to 600' d/s of Cameron Rd.	13.42	$ 875,000	15.34
20.	16.	BUL	1600' d/s to 950' d/s of North Creekwood Dr.	3.18	$ 245,000	13.00
21.	30.	EBO	Just u/s of Gillis Park to 100 ft d/s of Cumberland Road	5.92	$ 315,000	18.78
22.	80.	WLR	From 450' above mouth of Waller Creek to 200' u/s of E. 9th St.	9.48	$ 1,100,000	8.61
23.	52.	SHL	From W. 25th St. to W. 28 1/2 th St.	5.39	$ 1,050,000	5.13
24.	33.	FOR	From Harold Ct. to Lott Ave.	9.54	$ 735,000	12.98
25.	21.	BUL	3000' u/s of Bridge Floral Park Rd. (Tributary No. 2)	3.71	$ 15,000	247.60
26.	2.	BAR	Near Dip Cove and Barton Hills Dr. (12,000' u/s of Barton Springs Rd.)	1.59	$ 80,000	19.85
27.	25.	CNT	New CC, from confluence with Colorado River to 600 ft u/s of confluence	8.99	$ 180,000	49.95
28.	77.	WAL	Tx. - New Orleans R.R. crossing to 500' u/s (Tributary No. 1)	4.27	$ 175,000	24.38
29.	88.	WMS	1500' d/s of 1st St. to 700' u/s of Emerald Forest Dr.	10.55	$ 1,975,000	5.34
30.	31.	EBO	El Paso Street to Lightsey Road	11.13	$ 735,000	15.14
31.	42.	JOH	From 50' d/s of Bowman Ave. to 350' u/s of Margranita Crescent.	2.58	$ 490,000	5.26
32.	70.	WAL	600' d/s of Loyola Ln. to 3600' u/s of Loyola Ln.	35.36	$ 450,000	78.57
33.	28.	EBO	From 600 ft u/s of S. 1st St. Crossing (1st) to 2300 ft u/s of S. 1st St. Crossing (1st)	6.61	$ 595,000	11.11
34.	51.	SHL	From W. 15th St. to 400' d/s of Windsor Rd.	17.35	$ 825,000	21.02
35.	14.	BOG	From 300' d/s of E. 12th St. to E. 19th St.	8.67	$ 800,000	10.84
36.	13.	BOG	From 150' d/s of E. 11th St. to 100' u/s of the Tx. New Orleans R.R.	16.17	$ 900,000	17.96
37.	7.	BLU	Academy Dr. to East Side Dr.	2.89	$ 175,000	16.53
38.	41.	JOH	From 100' d/s of Griswold Ln. to 500' u/s.	3.90	$ 210,000	18.57
39.	64.	TAN	From 150' d/s of Bennett St. to Helen St.	1.53	$ 210,000	7.29
40.	32.	FOR	From 300' d/s of the Missouri-Kansas Railroad to 1800' u/s.	10.56	$ 525,000	20.10

Figure 5-3: Example Erosion Feasibility Matrix Application for Pond Capital Solutions

Wshed	Reach		d.s. of site	Trib	Tributary		d.s. of site	Capt vol (ac-ft)
WLN	WLN-06	140	50%	0	0	0	0%	1045.8

			Design storm					EROSION CALCS: existing				Existing d.s. of BMP [eligible]			EROSION CALCS: gains			EROSION CALCS: BMP points				EROSION CALCS: Wshed points			
Geomorphic Reach ID	Pct. of Main Reach d.s. of BMP	Pct. of Main Reach +Trib d.s. of BMP	Time Interval	Current diff fr 10% IC (ac-ft)	Future diff fr 10%IC (ac-ft)	Pct. design storm capt'd: Current	Pct. design storm capt'd: Future	Type 3 Rank Score	Ratio of Ratios	Qs/L (tons/ft)	% design storm capt'd: future	Type 3 Rank Score	Ratio of Ratios - 1	Qs/L (tons/ft)	Type 3 Rank Score	Ratio of Ratios - 1	Qs/L (tons/ft)	Type 3 Rank Score	Ratio of Ratios - 1	Qs/L (tons/ft)	BMP Erosion Score	Type 3 Rank Score	Ratio of Ratios - 1	Qs/L (tons/ft)	Total Wshed Points Possible
WLN-01	100.0%	100.0%	2-year	921.8	2,137.6	100.0%	48.9%	16.77	4.29	142.4	48.9%	16.77	3.29	142.4	8.20	1.61	69.7	1.23	6.0	7.3	14.6	2.52	15.0	15.0	32.5
WLN-02	100.0%	100.0%	2-year	868.0	2,081.9	100.0%	50.2%	100.00	4.33	142.7	50.2%	100.00	3.33	142.7	50.23	1.67	71.7	7.53	6.3	7.5	21.3	15.00	15.0	15.0	45.0
WLN-03	100.0%	100.0%	2-year	320.8	1,305.2	100.0%	80.1%	100.00	5.50	129.4	80.1%	100.00	4.50	129.4	80.12	3.61	103.6	12.02	13.5	10.9	36.4	15.00	15.0	13.6	43.6
WLN-04	100.0%	100.0%	2-year	273.7	1,113.6	100.0%	93.9%	100.00	5.09	110.2	93.9%	100.00	4.09	110.2	93.91	3.84	103.5	14.09	14.4	10.9	39.4	15.00	15.0	11.6	41.6
WLN-05	100.0%	100.0%	2-year	282.6	1,036.2	100.0%	100.0%	22.93	5.00	106.4	100.0%	22.93	4.00	106.4	22.93	4.00	106.4	3.44	15.0	11.2	29.6	3.44	15.0	11.2	29.6
WLN-06	50.0%	50.0%	2-year	278.3	1,020.3	100.0%	100.0%	19.57	2.90	48.7	100.0%	9.79	0.95	24.3	9.79	0.95	24.3	1.47	3.6	2.6	7.6	2.94	10.9	5.1	18.9
WLN-07	-	-	2-year	294.8	995.0	100.0%	100.0%	12.88	2.90	101.1	100.0%	-	-	-	-	-	-	-	-	-	-	1.93	10.9	10.6	23.4
WLN-08	-	-	2-year	259.3	875.3	100.0%	100.0%	100.00	2.90	53.1	100.0%	-	-	-	-	-	-	-	-	-	-	15.00	10.9	5.6	31.5
WLN-09	-	-	2-year	249.4	742.9	100.0%	100.0%	20.47	2.85	47.5	100.0%	-	-	-	-	-	-	-	-	-	-	3.07	10.7	5.0	18.8
WLN-10	-	-	2-year	196.9	501.7	100.0%	100.0%	19.72	2.70	30.0	100.0%	-	-	-	-	-	-	-	-	-	-	2.96	10.1	3.2	16.2
WLN-11	-	-	2-year	184.8	488.6	100.0%	100.0%	67.28	4.13	86.3	100.0%	-	-	-	-	-	-	-	-	-	-	10.09	15.0	9.1	34.2
WLN-12	-	-	2-year	179.0	473.4	100.0%	100.0%	22.14	2.80	77.6	100.0%	-	-	-	-	-	-	-	-	-	-	3.32	10.5	8.2	22.0
WLN-13	-	-	2-year	149.8	446.3	100.0%	100.0%	56.61	4.17	94.9	100.0%	-	-	-	-	-	-	-	-	-	-	8.49	15.0	10.0	33.5
WLN-14	-	-	2-year	39.4	225.1	100.0%	100.0%	15.55	2.95	19.6	100.0%	-	-	-	-	-	-	-	-	-	-	2.33	11.1	2.1	15.5
WLN-15	-	-	2-year	18.2	133.8	100.0%	100.0%	16.33	2.90	29.9	100.0%	-	-	-	-	-	-	-	-	-	-	2.45	10.9	3.1	16.5
WLN-16	-	-	2-year	13.2	80.8	100.0%	100.0%	9.54	5.00	50.3	100.0%	-	-	-	-	-	-	-	-	-	-	1.43	15.0	5.3	21.7
WLN-T01-1	-	-	1-year	3.6	8.6	100.0%	100.0%	43.29	1.73	0.8	100.0%	-	-	-	-	-	-	-	-	-	-	6.49	6.5	0.1	13.1
WLN-T03-1	-	-	2-year	21.0	129.0	100.0%	100.0%	28.37	6.20	35.8	100.0%	-	-	-	-	-	-	-	-	-	-	4.26	15.0	3.8	23.0
WLN-T03-2	-	-	2-year	-	78.3	-	100.0%	16.16	6.20	24.5	100.0%	-	-	-	-	-	-	-	-	-	-	2.42	15.0	2.6	20.0
WLN-T03-3	-	-	2-year	-	70.4	-	100.0%	14.03	6.20	31.6	100.0%	-	-	-	-	-	-	-	-	-	-	2.10	15.0	3.3	20.4
WLN-T07-1	-	-	2-year	68.6	101.1	100.0%	100.0%	17.68	2.40	15.7	100.0%	-	-	-	-	-	-	-	-	-	-	2.65	9.0	1.6	13.3
WLN-T07-2	-	-	2-year	51.6	66.6	100.0%	100.0%	4.80	2.04	7.9	100.0%	-	-	-	-	-	-	-	-	-	-	0.72	7.7	0.8	9.2
WLN-T07-3	-	-	1-year	36.1	42.5	100.0%	100.0%	-	1.75	5.2	100.0%	-	-	-	-	-	-	-	-	-	-	-	6.6	0.6	7.1
WLN-T07-T7	-	-	1-year	7.1	11.2	100.0%	100.0%	4.24	1.88	3.2	100.0%	-	-	-	-	-	-	-	-	-	-	0.64	7.0	0.3	8.0
WLN-T08-1	-	-	2-year	14.0	33.9	100.0%	100.0%	20.29	2.82	4.6	100.0%	-	-	-	-	-	-	-	-	-	-	3.04	10.6	0.5	14.1
WLN-T08-2	-	-	2-year	18.0	34.7	100.0%	100.0%	4.65	2.35	7.5	100.0%	-	-	-	-	-	-	-	-	-	-	0.70	8.8	0.8	10.3
WLN-T08-3	-	-	2-year	17.8	31.5	100.0%	100.0%	19.35	2.70	4.5	100.0%	-	-	-	-	-	-	-	-	-	-	2.90	10.1	0.5	13.5
WLN-T09-1	-	-	2-year	12.0	99.2	100.0%	100.0%	43.77	4.20	141.8	100.0%	-	-	-	-	-	-	-	-	-	-	6.57	15.0	14.9	36.5
WLN-WEL-1	-	-	2-year	31.7	178.6	100.0%	100.0%	9.41	3.60	54.0	100.0%	-	-	-	-	-	-	-	-	-	-	1.41	13.5	5.7	20.6
WLN-WEL-2	-	-	2-year	30.3	176.6	100.0%	100.0%	44.66	3.80	58.6	100.0%	-	-	-	-	-	-	-	-	-	-	6.70	14.3	6.2	27.1
WLN-WEL-3	-	-	2-year	28.0	168.4	100.0%	100.0%	55.37	2.75	7.4	100.0%	-	-	-	-	-	-	-	-	-	-	8.30	10.3	0.8	19.4
WLN-WEL-4	-	-	2-year	16.9	111.8	100.0%	100.0%	100.00	4.40	24.5	100.0%	-	-	-	-	-	-	-	-	-	-	15.00	15.0	2.6	32.6
WLN-WEL-5	-	-	2-year	8.0	78.5	100.0%	100.0%	23.20	4.50	7.6	100.0%	-	-	-	-	-	-	-	-	-	-	3.48	15.0	0.8	19.3
WLN-WEL-6	-	-	2-year	4.4	38.3	100.0%	100.0%	14.12	7.80	10.2	100.0%	-	-	-	-	-	-	-	-	-	-	2.12	15.0	1.1	18.2
	6 No. of Reaches Affected																	39.78	58.8	50.4	148.9	174.48	415.2	180.3	769.9
																				normalized	94.7			pct. of total wshed pts	19.3%

Table 5-8: Top 40 Most Effective Pond Erosion Control Capital Solutions

Rank	Pond No.	Wshed	Location	BMP Type	Erosion Score
1.	**111a.**	**WAL**	**Walnut Creek Metro Park**	**Wet + BF + Eros**	**100.00**
2.	**110b.**	**WAL**	**N. of Criswell & Sprinkle Rd., along creek**	**Eros capt**	**94.66**
3.	111b.	WAL	Walnut Creek Metro Park	Eros capt	94.09
4.	111c.	WAL	Walnut Creek Metro Park	Wet + Eros	94.09
5.	110a.	WAL	N. of Criswell & Sprinkle Rd., along creek	Wet + BF + Eros	61.15
6.	110c.	WAL	N. of Criswell & Sprinkle Rd., along creek	Wet + Eros	60.55
7.	**104a.**	**WAL**	**SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)**	**Wet + BF + Eros**	**40.38**
8.	104b.	WAL	SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)	Eros capt	37.67
9.	104c.	WAL	SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)	Wet + Eros	37.67
10.	**46b.**	**CNT**	**NE of Country C. Dr. & Riverside**	**Eros capt**	**31.06**
11.	**112a.**	**WAL**	**SW of Duval Rd. & S-bound MoPac**	**Wet + BF + Eros**	**29.02**
12.	112b.	WAL	SW of Duval Rd. & S-bound MoPac	Eros capt	26.16
13.	112c.	WAL	SW of Duval Rd. & S-bound MoPac	Wet + Eros	26.16
14.	**102a.**	**WAL**	**SE of McNeil Dr. & Parmer Ln.**	**Wet + BF + Eros**	**24.00**
15.	**103b.**	**WAL**	**W. of Council Bluff Dr., N. of Parmer Ln.W.**	**Eros capt**	**23.06**
16.	103a.	WAL	W. of Council Bluff Dr., N. of Parmer Ln.W.	Wet + BF + Eros	23.06
17.	103c.	WAL	W. of Council Bluff Dr., N. of Parmer Ln.W.	Wet + Eros	23.06
18.	46c.	CNT	NE of Country C. Dr. & Riverside	Wet + Eros	21.82
19.	102b.	WAL	SE of McNeil Dr. & Parmer Ln.	Eros capt	21.71
20.	102c.	WAL	SE of McNeil Dr. & Parmer Ln.	Wet + Eros	21.71
21.	46a.	CNT	NE of Country C. Dr. & Riverside	Wet + BF + Eros	21.37
22.	**106a.**	**WAL**	**W. Cow Path, Duval & Bull Run, near 183**	**Wet + BF + Eros**	**18.12**
23.	106b.	WAL	W. Cow Path, Duval & Bull Run, near 183	Eros capt	16.91
24.	106c.	WAL	W. Cow Path, Duval & Bull Run, near 183	Wet + Eros	16.91
25.	**131b.**	**WMS**	**S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)**	**Eros capt**	**15.08**
26.	**37a.**	**CNT**	**Mabel Davis Park**	**Wet + BF + Eros**	**13.47**
27.	37b.	CNT	Mabel Davis Park	Eros capt	12.86
28.	37c.	CNT	Mabel Davis Park	Wet + Eros	12.86
29.	**137b.**	**WMS**	**S. of intersection of Convict Hill Rd., Brush Country & MoPac**	**Eros capt**	**11.58**
30.	131f.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Irrig.	11.43
31.	**38b.**	**CNT**	**SE of E. Oltorf St. & Douglas**	**Eros capt**	**10.99**
32.	**39a.**	**CNT**	**E. of Co. Club Dr. & S of Riverside by ACC**	**Wet + BF + Eros**	**10.58**
33.	39b.	CNT	E. of Co. Club Dr. & S of Riverside by ACC	Eros capt	9.53
34.	39c.	CNT	E. of Co. Club Dr. & S of Riverside by ACC	Wet + Eros	9.53
35.	**33a.**	**BUL**	**ponds at Great Hills Golf Course**	**Wet + BF + Eros**	**9.00**
36.	33f.	BUL	ponds at Great Hills Golf Course	Irrig.	8.87
37.	**130b.**	**WMS**	**@ N. end of Lancret Hill Dr. (N of Lost Valley & Wm Cannon & Brodie)**	**Eros capt**	**8.52**
38.	**124b.**	**WMS**	**NW of HEB @ Hwy. 290/71**	**Eros capt**	**8.44**
39.	**48b.**	**FOR**	**E. 51st and Manor**	**Eros capt**	**8.15**
40.	131c.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Wet + Eros	8.15

* Bolded facilities indicate the highest ranked configuration for a particular site; non-bolded facilities have a higher rated configuration also shown in this table.

Table 5-9: Top 40 Most Cost-Effective Pond Erosion Control Capital Solutions

Rank	Pond No.	Wshed	Location	BMP Type	Erosion Score	Capital Cost	Effect/Cost x 1,000,000
1.	**39b.**	**CNT**	**E. of Co. Club Dr. & S of Riverside by ACC**	**Eros capt**	**9.53**	**$ 219,047**	**43.52**
2.	**104b.**	**WAL**	**SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)**	**Eros capt**	**37.67**	**$ 884,809**	**42.57**
3.	**46b.**	**CNT**	**NE of Country C. Dr. & Riverside**	**Eros capt**	**31.06**	**$ 730,236**	**42.54**
4.	**111b.**	**WAL**	**Walnut Creek Metro Park**	**Eros capt**	**94.09**	**$ 2,928,554**	**32.13**
5.	39a.	CNT	E. of Co. Club Dr. & S of Riverside by ACC	Wet + BF + Eros	10.58	$ 349,671	30.26
6.	39c.	CNT	E. of Co. Club Dr. & S of Riverside by ACC	Wet + Eros	9.53	$ 334,188	28.52
7.	**102b.**	**WAL**	**SE of McNeil Dr. & Parmer Ln.**	**Eros capt**	**21.71**	**$ 835,270**	**25.99**
8.	46c.	CNT	NE of Country C. Dr. & Riverside	Wet + Eros	21.82	$ 846,516	25.77
9.	46a.	CNT	NE of Country C. Dr. & Riverside	Wet + BF + Eros	21.37	$ 848,352	25.19
10.	**37b.**	**CNT**	**Mabel Davis Park**	**Eros capt**	**12.86**	**$ 515,933**	**24.93**
11.	**110b.**	**WAL**	**N. of Criswell & Sprinkle Rd., along creek**	**Eros capt**	**94.66**	**$ 3,816,420**	**24.80**
12.	**131b.**	**WMS**	**S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)**	**Eros capt**	**15.08**	**$ 620,199**	**24.31**
13.	104a.	WAL	SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)	Wet + BF + Eros	40.38	$ 1,673,647	24.13
14.	104c.	WAL	SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)	Wet + Eros	37.67	$ 1,611,399	23.37
15.	**112b.**	**WAL**	**SW of Duval Rd. & S-bound MoPac**	**Eros capt**	**26.16**	**$ 1,160,587**	**22.54**
16.	**103b.**	**WAL**	**W. of Council Bluff Dr., N. of Parmer Ln.W.**	**Eros capt**	**23.06**	**$ 1,043,727**	**22.09**
17.	**42b.**	**CNT**	**S of Ponca cul de sac**	**Eros capt**	**4.20**	**$ 192,784**	**21.80**
18.	**44b.**	**CNT**	**W of Kemp**	**Eros capt**	**6.28**	**$ 316,439**	**19.84**
19.	**41b.**	**CNT**	**Trib N of Riverside ACC campus**	**Eros capt**	**5.15**	**$ 290,373**	**17.72**
20.	111a.	WAL	Walnut Creek Metro Park	Wet + BF + Eros	100.00	$ 5,662,985	17.66
21.	111c.	WAL	Walnut Creek Metro Park	Wet + Eros	94.09	$ 5,469,895	17.20
22.	**45b.**	**CNT**	**Between Riverside Farms and Grove**	**Eros capt**	**4.91**	**$ 290,212**	**16.93**
23.	102a.	WAL	SE of McNeil Dr. & Parmer Ln.	Wet + BF + Eros	24.00	$ 1,496,844	16.03
24.	102c.	WAL	SE of McNeil Dr. & Parmer Ln.	Wet + Eros	21.71	$ 1,434,476	15.13
25.	**38b.**	**CNT**	**SE of E. Oltorf St. & Douglas**	**Eros capt**	**10.99**	**$ 732,005**	**15.01**
26.	37c.	CNT	Mabel Davis Park	Wet + Eros	12.86	$ 860,444	14.95
27.	37a.	CNT	Mabel Davis Park	Wet + BF + Eros	13.47	$ 916,616	14.69
28.	112a.	WAL	SW of Duval Rd. & S-bound MoPac	Wet + BF + Eros	29.02	$ 2,078,215	13.96
29.	**126b.**	**WMS**	**SW of Beckett Trail & Kayview Dr. (Davis Ln. & Beckett, Dick Nichols Park)**	**Eros capt**	**7.43**	**$ 537,889**	**13.81**
30.	**130b.**	**WMS**	**@ N. end of Lancret Hill Dr. (N of Lost Valley & Wm Cannon & Brodie)**	**Eros capt**	**8.52**	**$ 629,219**	**13.54**
31.	103c.	WAL	W. of Council Bluff Dr., N. of Parmer Ln.W.	Wet + Eros	23.06	$ 1,717,198	13.43
32.	44a.	CNT	W of Kemp	Wet + BF + Eros	6.94	$ 518,694	13.37
33.	112c.	WAL	SW of Duval Rd. & S-bound MoPac	Wet + Eros	26.16	$ 2,003,088	13.06
34.	103a.	WAL	W. of Council Bluff Dr., N. of Parmer Ln.W.	Wet + BF + Eros	23.06	$ 1,796,897	12.83
35.	44c.	CNT	W of Kemp	Wet + Eros	6.28	$ 495,390	12.67
36.	42c.	CNT	S of Ponca cul de sac	Wet + Eros	3.23	$ 259,209	12.46
37.	**122b.**	**WMS**	**Covered Bridge**	**Eros capt**	**4.28**	**$ 348,817**	**12.26**
38.	**105b.**	**WAL**	**S. of Howard Ln. & E. of Scofield Ridge**	**Eros capt**	**6.88**	**$ 561,509**	**12.25**
39.	**106b.**	**WAL**	**W. Cow Path, Duval & Bull Run, near 183**	**Eros capt**	**16.91**	**$ 1,415,449**	**11.95**
40.	**40b.**	**CNT**	**NE of Faro**	**Eros capt**	**2.75**	**$ 233,109**	**11.81**

* Bolded facilities indicate the highest ranked configuration for a particular site; non-bolded facilities have a higher rated configuration also shown in this table.

Nine parameters were considered for evaluation of prospective land and conservation easement sites. The nine parameters and their relative weightings are presented below:

Evaluation Parameter	Weighting
1. Avoided Pollution	20.0 %
2. Biological Resource Protection	6.4 %
3. Endangered Species Protection	9.6 %
4. Recreation Benefits/Aesthetics	7.8 %
5. Mitigation Potential	8.0 %
6. Baseflow Protection	14.7 %
7. Recharge Protection	12.4 %
8. Location	8.9 %
9. Water Supply Watershed Status	12.2 %
Totals	100 %

The pairwise comparison method was used to determine the individual weightings for each of these nine parameters. In the pairwise comparison method, each identified parameter is compared individually with every other parameter. With each paired comparison, each of the two parameters is assigned a raw importance score between 0.0 and 1.0, with the total paired score equal to 1.0. Based upon the pairwise comparison method, each of the nine parameters was weighted with the total of all weights equal to 1.0.

Individual prospective land or conservation easement acquisition sites are then assigned an integer value between 0 and 3; these values are weighted; and the total benefit score for the acquisition site is compiled. Table 5-10 presents descriptions of the nine evaluation parameters and the criteria used for assignment of 0-3 scores for each parameter. Table 5-11 presents the results of the pairwise comparison process.

Table 5-10: Potential Benefits of Land Acquisition or Conservation Easement Options: Identified Factors, Descriptions, Values, Percent Relative Importance, and Rank of Importance Values

Benefit	Description	Values	Relative Importance	Rank
Avoided pollution	Pollution avoided by prevention of development. Determinations are based on size, jurisdiction (applicable regulations, ordinances, and laws), predicted impervious cover, and predicted upland and instream loads.	3: Total size of 500 acres or more, not subject to COA water quality ordinances, predicted impervious cover 40% or more, and very high predicted upland and instream loads. (3 out of 4) 2: Total size 300 – 500 acres, subject to older COA water quality ordinances (pre-CWO), predicted impervious cover 30% or more, and high predicted upland and instream loads. (3 out of 4) 1: Total size 100 - 300 acres, subject to current COA water quality ordinances (not including SOS), predicted impervious cover 20% or more, and medium predicted upland and instream loads. (3 out of 4) 0: Total size less than 100 acres, subject to current COA water quality ordinances (including SOS), predicted impervious cover less than 20%, and low predicted upland and instream loads. (3 out of 4)	20.0%	1
Biological resource protection	Occurrence of priority woodlands, priority prairies, and Critical Environmental Features (CEFs, e.g., springs, caves, sinkholes, rimrocks, and wetlands).	3: Identified as or meets definition of high priority woodlands and/or prairies, or is known to include or considered likely to include multiple significant CEFs of more than one type. 2: Identified as or meets definition of medium priority woodlands and/or prairies, or is known to include or considered likely to include multiple significant CEFs of only one type. 1: Identified as or meets definition of low priority woodlands and/or prairies, or is known to include or considered likely to include at least one significant CEF. 0: Does not include characteristics of priority woodlands or prairies, and is not known to include or considered likely to include significant CEFs.	6.4%	9
Endangered species protection	Habitat protection benefits for endangered species, and compatibility with Balcones Canyonlands Preserve (BCP). Habitat determinations are based on the BCP maps. Scores are based on habitat protection for the Barton Springs salamander, karst invertebrates (karst zones 1 and 2, which includes the Edwards Aquifer recharge zone), golden-cheeked warbler (GCW zones 1 and 2), and black-capped vireo (BCV)	3: Is within or upstream of the Barton Springs Edwards Aquifer recharge zone, or is within BCP preserve boundary line or BCP karst protection area. 2: Includes karst invertebrate (KI), golden-cheeked warbler (GCW) or black-capped vireo (BCV) habitat, and is adjacent to BCP preserve boundary line or BCP karst protection area. 1: Includes KI, GCW or BCV habitat; but is isolated from BCP preserve boundary line and BCP karst protection areas. 0: No endangered species habitat; and is adjacent to or isolated from BCP preserve boundary line and BCP karst protection areas.	9.6%	5
Recreation benefits/ aesthetics	Value as parkland, preserve, or other open space use.	3: High value as parkland, preserve, or other open space use, and under consideration for acquisition. 2: High value as parkland, preserve, or other open space use, and under consideration for conservation easement. 1: Medium value as parkland, preserve, or other open space use, and under consideration for conservation easement. 0: Low value as parkland, preserve, or other open space use.	7.8%	8

Table 5-10: Potential Benefits of Land Acquisition or Conservation Easement Options: Identified Factors, Descriptions, Values, Percent Relative Importance, and Rank of Importance Values
(*Continued*)

Benefit	Description	Values	Relative Importance	Rank
Mitigation potential	Potential value for future water quality retrofit projects.	3: High potential for future water quality retrofit project; previously identified as a candidate site. 2: Medium potential for future water quality retrofit project; previously considered as a candidate site. 1: Low potential for future water quality retrofit project; merits consideration as a candidate site. 0: Not useful for future water quality retrofit project.	8.0%	7
Baseflow protection	Protection of source water volume.	3: High ratio of main and tributary channel length to total tract size (in 75th percentile of all tracts under evaluation). 2: Lower ratio of main and tributary channel length to total tract size (not in 75th percentile of all tracts under evaluation). 1: Within Edwards Aquifer contributing zone 0: Within Edwards Aquifer recharge zone. (NOTE: Main and tributary channels includes second and third order streams; streams that generally form the tract boundary count for half the boundary length.)	14.7%	2
Recharge protection	Protection of Barton Springs Edwards Aquifer recharge.	3: Within recharge zone, and has high total length of main and tributary channel (in 75th percentile of all tracts under evaluation in recharge zone). 2: Within recharge zone, but has lower total length of main and tributary channel (not in 75th percentile of all tracts under evaluation in recharge zone). 1: Within contributing zone, above recharge zone. 0: No significant aquifer recharge potential. (NOTE: Main and tributary channels includes second and third order streams; streams that generally form the tract boundary count for half the boundary length.)	12.4%	3
Location	Strategic contiguity, and linkage with other parks, preserves and neighborhoods for hike/bike trails and wildlife habitat.	3: High value for contiguity or linkage; contiguous with or links two or more important areas. 2: Medium value for contiguity or linkage; contiguous with one or more important areas, or may be useful for future linkage. 1: Low value for contiguity or linkage; may be useful in future for contiguity or linkage. 0: No value for contiguity or linkage.	8.9%	6
Water supply watershed	Watershed benefited by land protection.	3: Lake Austin, Bull Creek 2: Barton Springs zone creeks 1: Other Town Lake watersheds 0: Other	12.2%	4

Table 5-11: Relative Importance of Potential Benefits of Land Acquisition or Conservation Easement Options, Determined by Pairwise Comparisons

	Avoided pollution	Biological resource protection	Endangered species protection	Recreation benefits/ aesthet.	Mitigation potential	Baseflow protection	Recharge protection	Location	Water supply watershed	"Dummy criterion"	Sum of raw importance scores	Percent relative importance	Rank
Avoided pollution		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	9.0	20.0%	1
Biological resource protection	0.0		0.4	0.5	0.2	0.2	0.2	0.2	0.2	1.0	2.9	6.4%	9
Endangered species protection	0.0	0.6		0.7	0.7	0.2	0.2	0.7	0.2	1.0	4.3	9.6%	5
Recreation benefits/ aesthetics	0.0	0.5	0.3		0.6	0.2	0.2	0.5	0.2	1.0	3.5	7.8%	8
Mitigation potential	0.0	0.8	0.3	0.4		0.2	0.2	0.4	0.3	1.0	3.6	8.0%	7
Baseflow protection	0.0	0.8	0.8	0.8	0.8		0.8	0.8	0.8	1.0	6.6	14.7%	2
Recharge protection	0.0	0.8	0.8	0.8	0.8	0.2		0.8	0.4	1.0	5.6	12.4%	3
Location	0.0	0.8	0.3	0.5	0.6	0.2	0.2		0.4	1.0	4.0	8.9%	6
Water supply watershed	0.0	0.8	0.8	0.8	0.7	0.2	0.6	0.6		1.0	5.5	12.2%	4
"Dummy criterion"	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0%	10
TOTALS											45	100.0%	

5.2 Feasibility Matrix Development for Regulatory Solutions

5.2.1 Water Quality Feasibility Matrix Development for Regulatory Solutions

5.2.2 Flood Control Feasibility Matrix Development for Regulatory Solutions

5.2.3 Erosion Control Feasibility Matrix Development for Regulatory Solutions

5.3 Feasibility Matrix Development for Programmatic Solutions

5.3.1 Water Quality Feasibility Matrix Development for Programmatic Solutions

5.3.2 Flood Control Feasibility Matrix Development for Programmatic Solutions

5.3.3 Erosion Control Feasibility Matrix Development for Programmatic Solutions

5.4 Summary Matrix

Table 5-12 presents the top 40 integrated solutions based upon benefit score. Table 5-13 presents the top 40 integrated solutions based upon benefit-cost score. Appendix D-2 presents the results of the Summary Matrix (the Integrated Solutions Assessment Results).

Table 5-12: Top 40 Integrated Solutions by Benefit-Cost Score

Rank	Appendix Unique No.	Wshed	Project Name	Solution Type	Technical Effectiveness + Sustainability Score	Capital Cost	Norm. Final Cost Effect Score
1.	21.	BUL	3000' u/s of Bridge Floral Park Rd. (Tributary No. 2)	Bank Stabilization**	1.31	$ 15,000	100.00
2.	84.	WLR	350' u/s of Koenig Ln.	Bank Stabilization**	1.05	$ 20,000	67.00
3.	22.	BUL	3400' u/s of confluence with Bull Creek main stem (Tributary No. 3)	Bank Stabilization**	0.63	$ 15,000	39.94
4.	82.	WLR	200' d/s of W. 31st St.	Bank Stabilization**	0.54	$ 20,000	29.27
5.	26.	CNT	New CC, from 100 ft d/s of Riverside Dr. Bridge to 50 ft u/s of Riverside Dr. Bridge	Bank Stabilization**	5.76	$ 165,000	26.17
6.	65.	WBO	From 700 feet d/s of Jewell Street extended to West Mary Street	Bank Stabilization**	10.32	$ 861,000	17.58
7.	19.	BUL	500' d/s to 300' u/s of Spicewood Springs Rd. (Tributary No. 2)	Bank Stabilization**	4.93	$ 240,000	16.80
8.	77.	WAL	Tx. - New Orleans R.R. crossing to 500' u/s (Tributary No. 1)	Bank Stabilization**	1.68	$ 175,000	16.07
9.	40.	JOH	From Stephen F. Austin Dr. to 350' u/s of Lake Austin Blvd.	Bank Stabilization**	4.79	$ 595,000	13.45
10.	41.	JOH	From 100' d/s of Griswold Ln. to 500' u/s.	Bank Stabilization**	2.11	$ 210,000	13.40
11.	36.	FOR	1650' to 250' d/s of Westminster Dr.	Bank Stabilization**	6.94	$ 575,000	12.60
12.	25.	CNT	New CC, from confluence with Colorado River to 600 ft u/s of confluence	Bank Stabilization**	3.12	$ 180,000	11.02
13.	39.	HRP	From u/s of IH 35 to 600 ft d/s of Reagan Terrace	Bank Stabilization**	2.05	$ 262,500	10.44
14.	68.	WBO	From Riverside Drive to Barton Springs Road	Bank Stabilization**	3.75	$ 420,000	9.93
15.	66.	WBO	From 1000 feet d/s of Cumberland Road extended to Cumberland Road	Bank Stabilization**	1.99	$ 350,000	9.47
16.	29.	EBO	From 300 ft u/s of S. 1st St. Crossing (2nd) to 200 ft u/s of Johanna Street	Bank Stabilization**	8.99	$ 971,000	9.07
17.	72.	WAL	2300' d/s of Highway 290 to 2100' u/s of Highway 290	Bank Stabilization**	12.62	$ 423,000	8.71
18.	60.	TAN	From 600' u/s of Oak Springs Dr. to 800' d/s of E. 12th St.	Bank Stabilization**	4.36	$ 385,000	8.39
19.	71.	WAL	2620' d/s of Manor Rd. to 800' u/s of Manor Rd.	Bank Stabilization**	13.37	$ 370,000	8.22
20.	83.	WLR	From 200' u/s of W. 46th St. to 600' D/s of E. 51st St.	Bank Stabilization**	2.27	$ 490,000	7.73
21.	31.	EBO	El Paso Street to Lightsey Road	Bank Stabilization**	5.82	$ 735,000	7.56
22.	9.	BLU	East Live Oak St. to 500' u/s of Oltorf St.	Bank Stabilization**	4.48	$ 595,000	7.18
23.	78.	WAL	500' d/s of Cedar Bend Dr. to 3500' u/s of Parmer Ln. (Wells Branch)	Bank Stabilization**	12.83	$1,550,000	6.80
24.	27.	EBO	From 200 ft d/s of Riverside Dr. to 200 ft. d/s of Congress Avenue	Bank Stabilization**	4.51	$ 560,000	6.72
25.	30.	EBO	Just u/s of Gillis Park to 100 ft d/s of Cumberland Road	Bank Stabilization**	2.53	$ 315,000	6.71
26.	7.	BLU	Academy Dr. to East Side Dr.	Bank Stabilization**	1.36	$ 175,000	6.49
27.	na	WAL	Austin Hills Mobile Home Estates	Buyout	130.00	$ 454,971	6.25
28.	75.	WAL	I.H. 35 to 100' u/s of Lamar Blvd.	Bank Stabilization**	14.18	$1,425,000	5.93
29.	73.	WAL	1250' d/s of Springdale Rd.	Bank Stabilization**	15.80	$ 782,000	5.90
30.	89.	WMS	1000' u/s of Westgate Blvd. to 3900' u/s of Westgate Blvd.	Bank Stabilization**	2.40	$ 455,000	5.86
31.	28.	EBO	From 600 ft u/s of S. 1st St. Crossing (1st) to 2300 ft u/s of S. 1st St. Crossing (1st)	Bank Stabilization**	3.11	$ 595,000	5.81
32.	81.	WLR	From E 15th St. to 250' d/s of M.L.K. Blvd.	Bank Stabilization**	2.34	$ 560,000	5.58
33.	33.	FOR	From Harold Ct. to Lott Ave.	Bank Stabilization**	4.21	$ 735,000	5.46
34.	11.	BMK	From 30 ft u/s of Bennett Avenue to Chevy Chase Drive	Bank Stabilization**	4.09	$ 840,000	5.42
35.	85.	WLR	From E. 26th St. to W. 30th St.	Bank Stabilization**	6.14	$ 775,000	5.40
36.	13.	BOG	From 150' d/s of E. 11th St. to 100' u/s of the Tx. New Orleans R.R.	Bank Stabilization**	6.09	$ 900,000	5.38
37.	63.	TAN	From Andover Pl. to 600' d/s of Cameron Rd.	Bank Stabilization**	5.60	$ 875,000	5.34
38.	76.	WAL	550' u/s of Water Park Rd. to 700' u/s of Duval Rd.	Bank Stabilization**	3.80	$ 805,000	5.25
39.	24.	CNT	New CC, from Oltorf Street to 500 ft d/s of Burleson Road	Bank Stabilization**	7.75	$1,050,000	5.03
40.	70.	WAL	600' d/s of Loyola Ln. to 3600' u/s of Loyola Ln.	Bank Stabilization**	13.97	$ 450,000	4.88

Table 5-12: Top 40 Integrated Solutions by Benefit Score (Technical Effectiveness+ Sustainability Score)

Rank	Appendix Unique No.	Wshed	Project Name	Solution Type	Technical Effectiveness + Sustainability Score	Capital Cost
1.	**na**	**WAL**	**Austin Hills Mobile Home Estates**	**Buyout**	**130.00**	**$ 454,971**
2.	**111a.**	**WAL**	**Walnut Creek Metro Park**	**Wet + BF + Eros**	**105.10**	**$ 5,662,985**
3.	111c.	WAL	Walnut Creek Metro Park	Wet + Eros	82.87	$ 5,469,895
4.	111b.	WAL	Walnut Creek Metro Park	Eros capt	66.54	$ 2,928,554
5.	**110a.**	**WAL**	**N. of Criswell & Sprinkle Rd., along creek**	**Wet + BF + Eros**	**66.37**	**$ 6,147,552**
6.	110b.	WAL	N. of Criswell & Sprinkle Rd., along creek	Eros capt	63.87	$ 3,816,420
7.	110c.	WAL	N. of Criswell & Sprinkle Rd., along creek	Wet + Eros	58.74	$ 6,141,468
8.	**na**	**WAL**	**Crystal Brook**	**Channelization, Flood Wall**	**54.79**	**$ 4,600,000**
9.	**104a.**	**WAL**	**SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)**	**Wet + BF + Eros**	**32.38**	**$ 1,673,647**
10.	**na**	**SHL**	**19th St Tunnel**	**Tunnel**	**31.60**	**$ 30,000,000**
11.	111d.	WAL	Walnut Creek Metro Park	Wet + BF	29.82	$ 3,120,223
12.	**131f.**	**WMS**	**S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)**	**Irrig.**	**29.81**	**$ 2,031,922**
13.	**112a.**	**WAL**	**SW of Duval Rd. & S-bound MoPac**	**Wet + BF + Eros**	**29.31**	**$ 2,078,215**
14.	**na**	**WAL**	**Pecan Mobile Home Park**	**Buyout**	**28.13**	**$ 1,755,556**
15.	104c.	WAL	SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)	Wet + Eros	25.53	$ 1,611,399
16.	110d.	WAL	N. of Criswell & Sprinkle Rd., along creek	Wet + BF	23.78	$ 3,699,592
17.	**122f.**	**WMS**	**Covered Bridge**	**Irrig.**	**22.88**	**$ 1,115,624**
18.	**na**	**LWA**	**Mearns Meadow Blvd**	**Storm Drain, Channelizatio**	**22.11**	**$ 5,328,000**
19.	na	LWA	Mearns Meadow Blvd	Concrete Lined Channel	22.11	$ 2,541,098
20.	**99a.**	**WBO**	**Trailer Park between Oltorf & Flanigan Cove**	**Wet + BF + Eros**	**21.96**	**$ 1,977,653**
21.	**27f.**	**BUL**	**W. of Old Lampasas Trail, N. of creek**	**Irrig.**	**21.42**	**$ 1,134,182**
22.	99d.	WBO	Trailer Park between Oltorf & Flanigan Cove	Wet + BF	20.86	$ 1,991,297
23.	131b.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Eros capt	20.68	$ 620,199
24.	104b.	WAL	SW of Howard Ln. W. & Lamar Blvd. (Wells Branch)	Eros capt	20.60	$ 884,809
25.	112c.	WAL	SW of Duval Rd. & S-bound MoPac	Wet + Eros	20.53	$ 2,003,088
26.	122a.	WMS	Covered Bridge	Wet + BF + Eros	19.87	$ 913,052
27.	**97a.**	**WBO**	**South Center St. and Audrey Ct.**	**Wet + BF + Eros**	**19.80**	**$ 1,042,877**
28.	**102a.**	**WAL**	**SE of McNeil Dr. & Parmer Ln.**	**Wet + BF + Eros**	**19.32**	**$ 1,496,844**
29.	**17a.**	**BLU**	**N. of Oltorf in Nature Pres.**	**Wet + BF + Eros**	**19.24**	**$ 759,328**
30.	**124f.**	**WMS**	**NW of HEB @ Hwy. 290/71**	**Irrig.**	**18.40**	**$ 1,146,629**
31.	131a.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Wet + BF + Eros	18.28	$ 1,575,442
32.	131c.	WMS	S. of end of Lone Oak Trail (off Jones Rd.) (NW of Brodie & Oakdale)	Wet + Eros	17.69	$ 1,573,462
33.	**na**	**FOR**	**Eleanor Dr**	**Channelization, Struct Repl**	**17.48**	**$ 1,860,989**
34.	**103a.**	**WAL**	**W. of Council Bluff Dr., N. of Parmer Ln.W.**	**Wet + BF + Eros**	**17.34**	**$ 1,796,897**
35.	**46b.**	**CNT**	**NE of Country C. Dr. & Riverside**	**Eros capt**	**17.07**	**$ 730,236**
36.	112b.	WAL	SW of Duval Rd. & S-bound MoPac	Eros capt	16.56	$ 1,160,587
37.	103c.	WAL	W. of Council Bluff Dr., N. of Parmer Ln.W.	Wet + Eros	16.36	$ 1,717,198
38.	**56d.**	**JOH**	**NE of L. Austin Blvd./MoPac/Cesar Chavez interchange**	**Wet + BF**	**15.87**	**$ 1,188,624**
39.	27a.	BUL	W. of Old Lampasas Trail, N. of creek	Wet + BF + Eros	15.85	$ 973,838
40.	**73.**	**WAL**	**1250' d/s of Springdale Rd.**	**Bank Stabilization****	**15.80**	**$ 782,000**

* Bolded facilities indicate the highest ranked configuration for a particular site; non-bolded facilities have a higher rated configuration also shown in this table.